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NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION

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# The Dvorak Technique

JACK BEVEN
NATIONAL HURRICANE CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

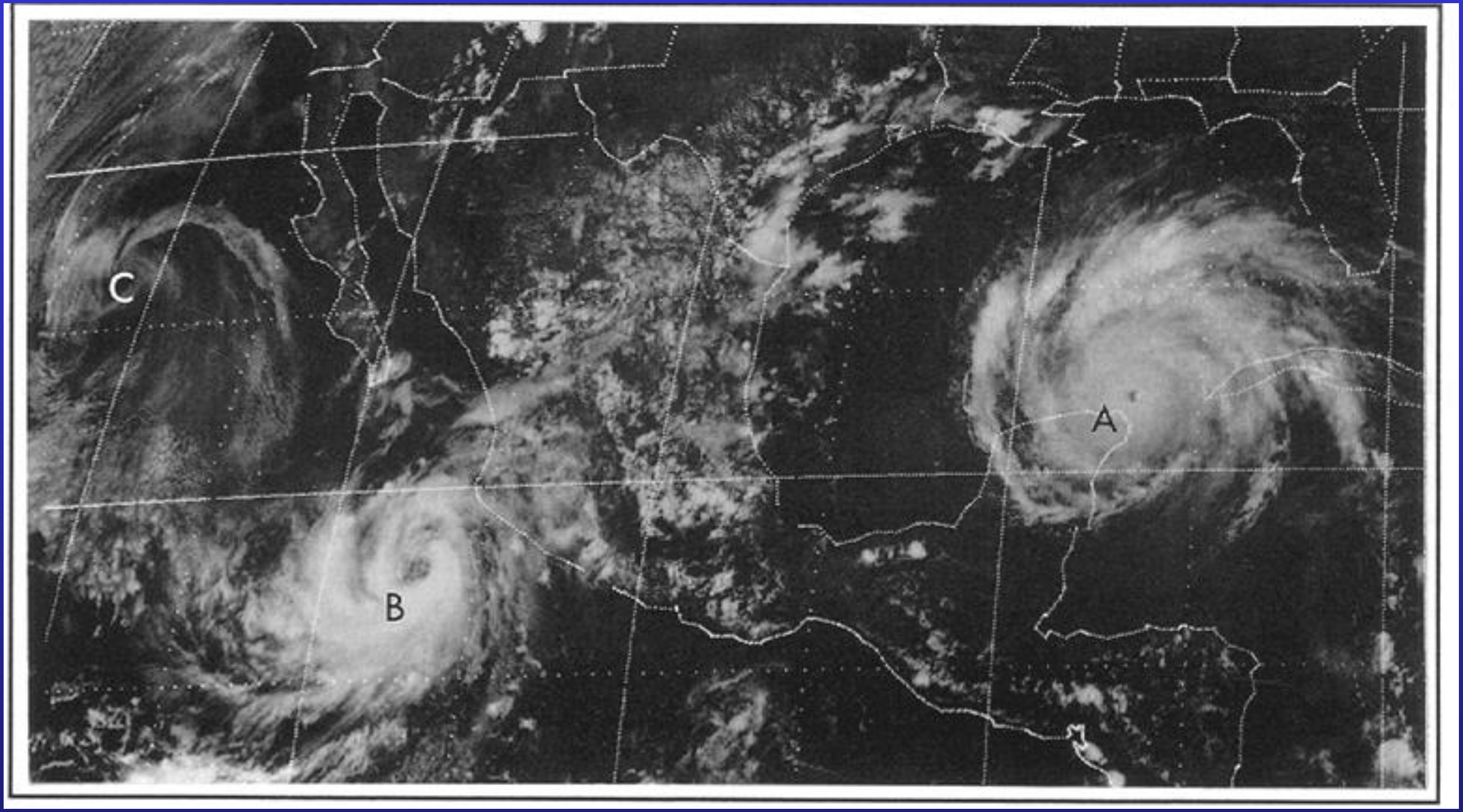
# What is the Dvorak Technique?

- A statistical method for <u>estimating</u> the intensity of tropical cyclones (TCs) from interpretation of satellite imagery
- Uses regular Infrared and Visible imagery
- Based on a "measurement" of the cyclone's convective cloud pattern and a set of rules
- It is used at tropical cyclone warning centers around the world

# What the Dvorak Technique isn't

- A direct measurement of wind, pressure, or any other meteorological variable associated with a tropical cyclone!
- A replacement for *in situ* measurements of a tropical cyclone

# Dvorak Technique Premise

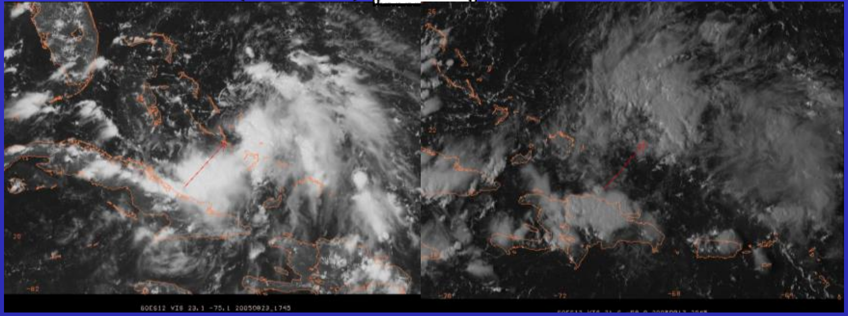


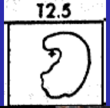
- There is a (imperfect) correlation between the intensity of a TC and its satellite observed cloud pattern during both development and decay.

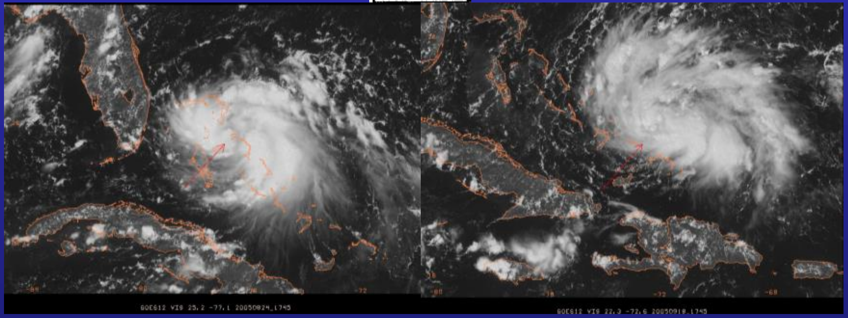
# TC Cloud Patterns – Developing

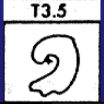
**Katrina (2005)**

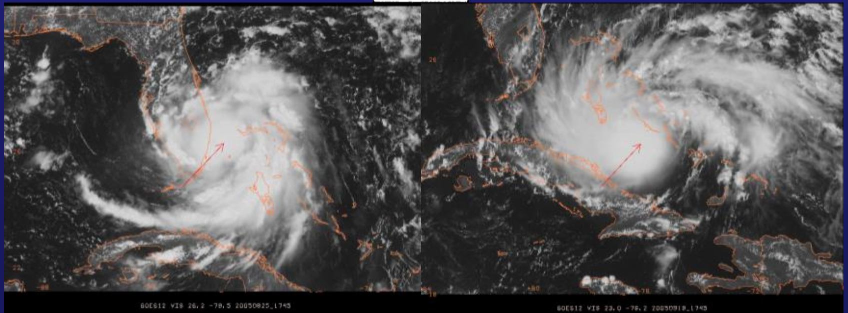
**Rita (2005)**



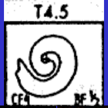




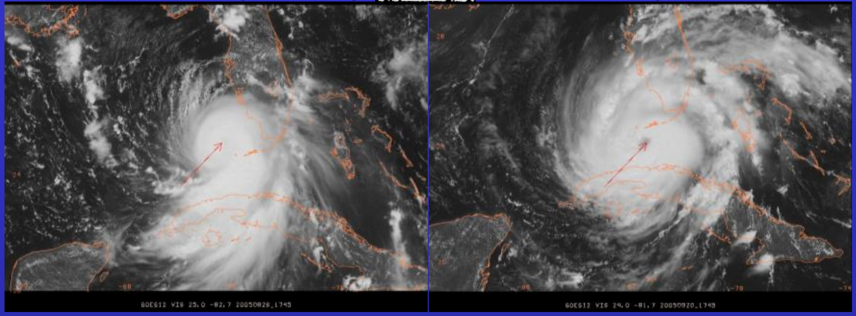


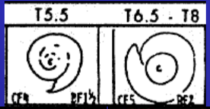


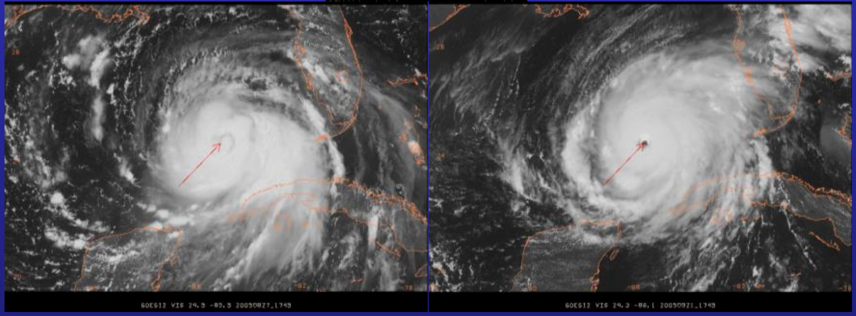
**Katrina (2005)**

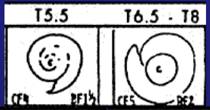


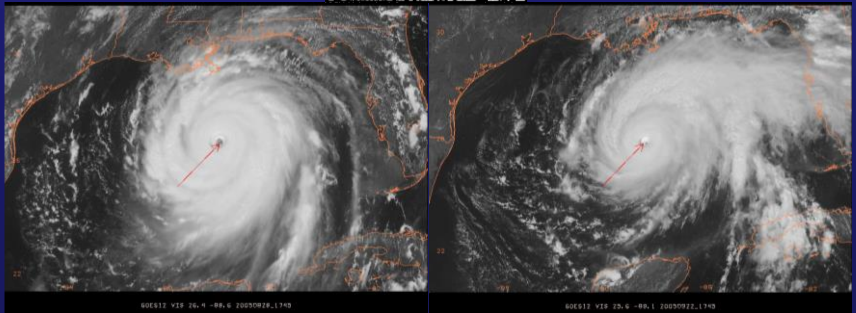
**Rita (2005)**





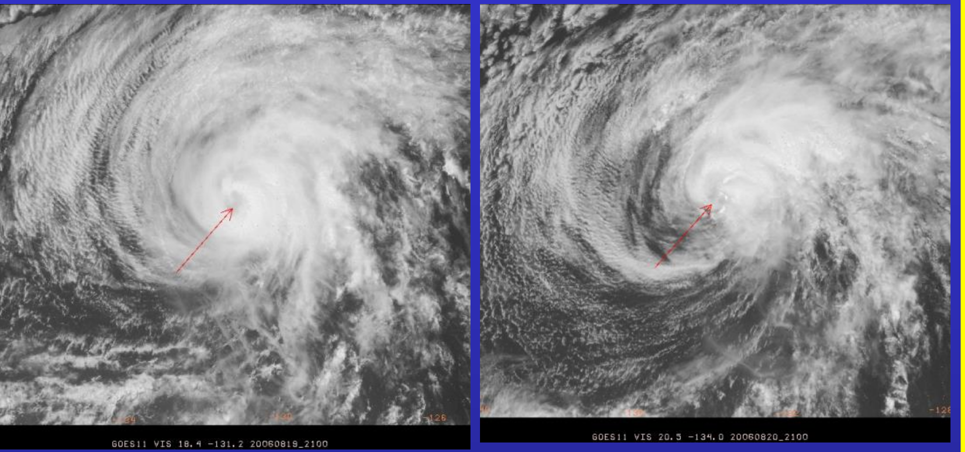




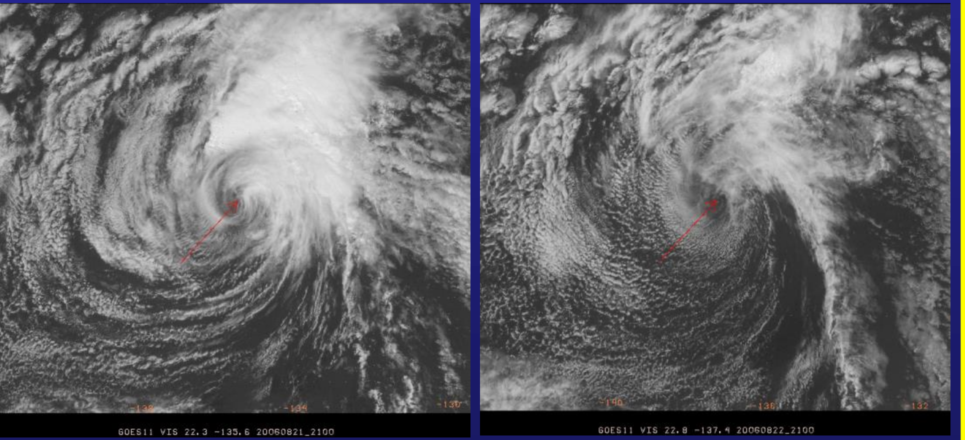


# TC Cloud Patterns - Weakening

## Hector 2006

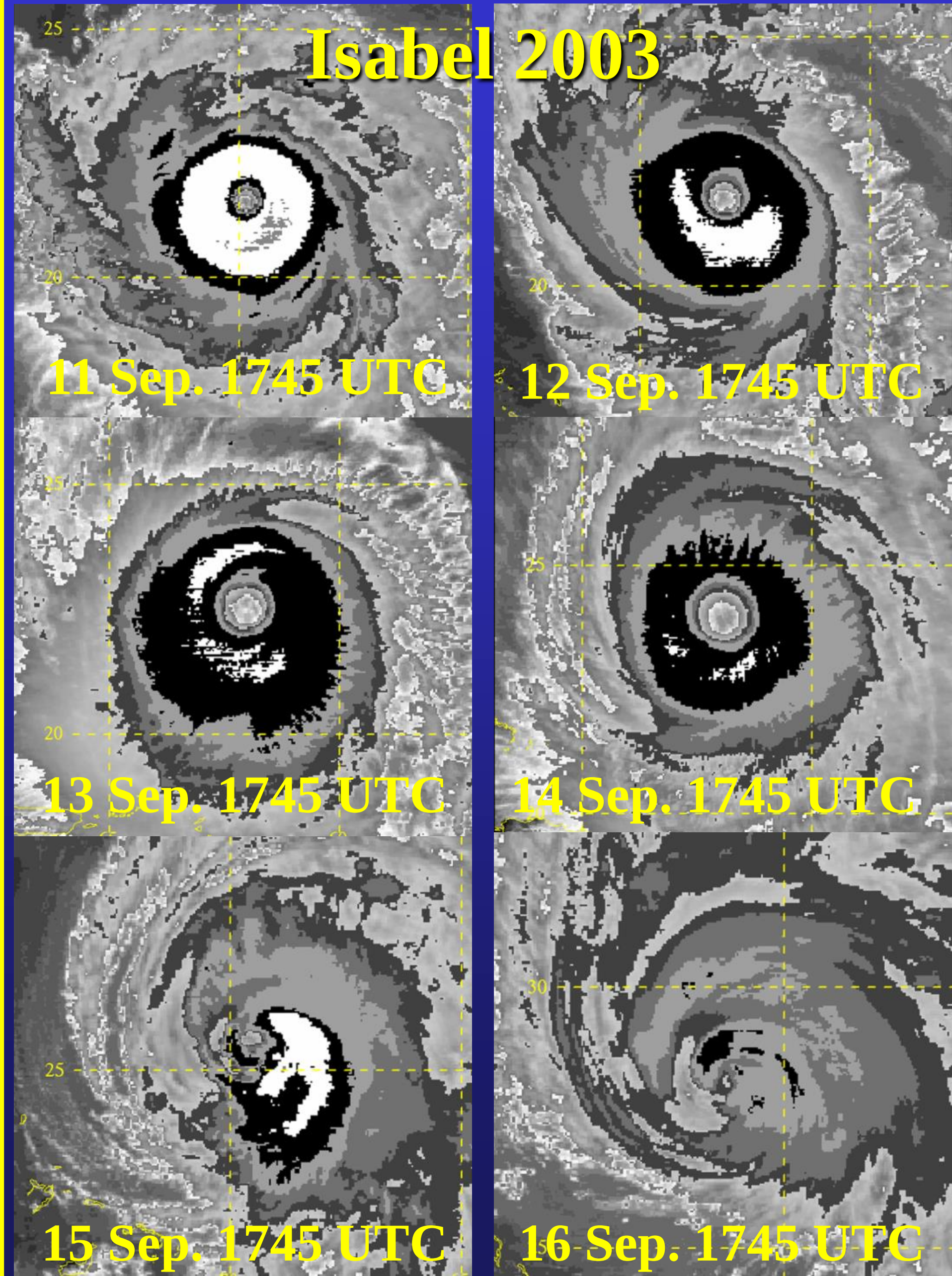


19 Aug. 2100 UTC 20 Aug. 2100 UTC



21 Aug. 2100 UTC 22 Aug. 2100 UTC

## Isabel 2003



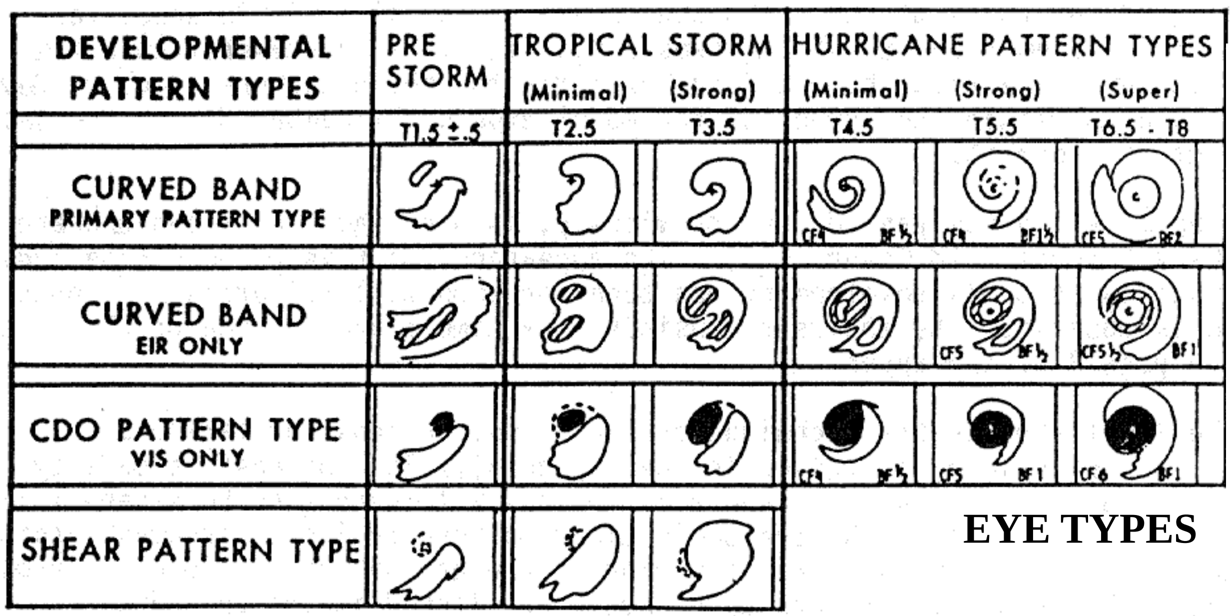
11 Sep. 1745 UTC 12 Sep. 1745 UTC

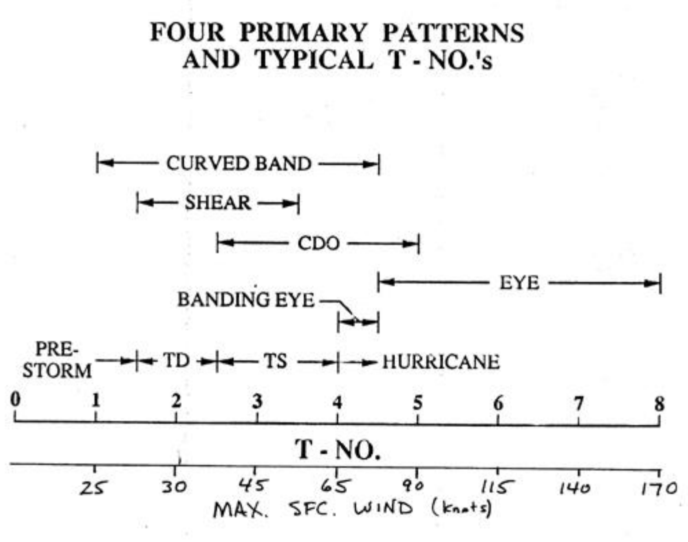
13 Sep. 1745 UTC 14 Sep. 1745 UTC

15 Sep. 1745 UTC 16 Sep. 1745 UTC

# Dvorak Technique Cloud Patterns

- Curved Band (VIS and IR)
- Shear (VIS and IR)
- Eye (VIS and IR)
- Central Dense Overcast (VIS)
- Embedded Center (IR)
- Central Cold Cover (VIS and IR)





# T-Numbers: How to Quantify the Cloud Patterns

- The Dvorak Technique quantifies TC intensity on a 1-8 scale (at 0.5 intervals) called T-Numbers, which are used in a variety of ways.
- The final output of the technique is the Current Intensity (CI) number.
- The CI number is driven by the Final-T (FT) Number.
- In turn, the FT is driven by the Data-T (DT) number, the Model Expected-T (MET) number, and the Pattern-T (PT or PAT) number.
- The DT is often created from other sub-numbers.

# Dvorak Technique Output

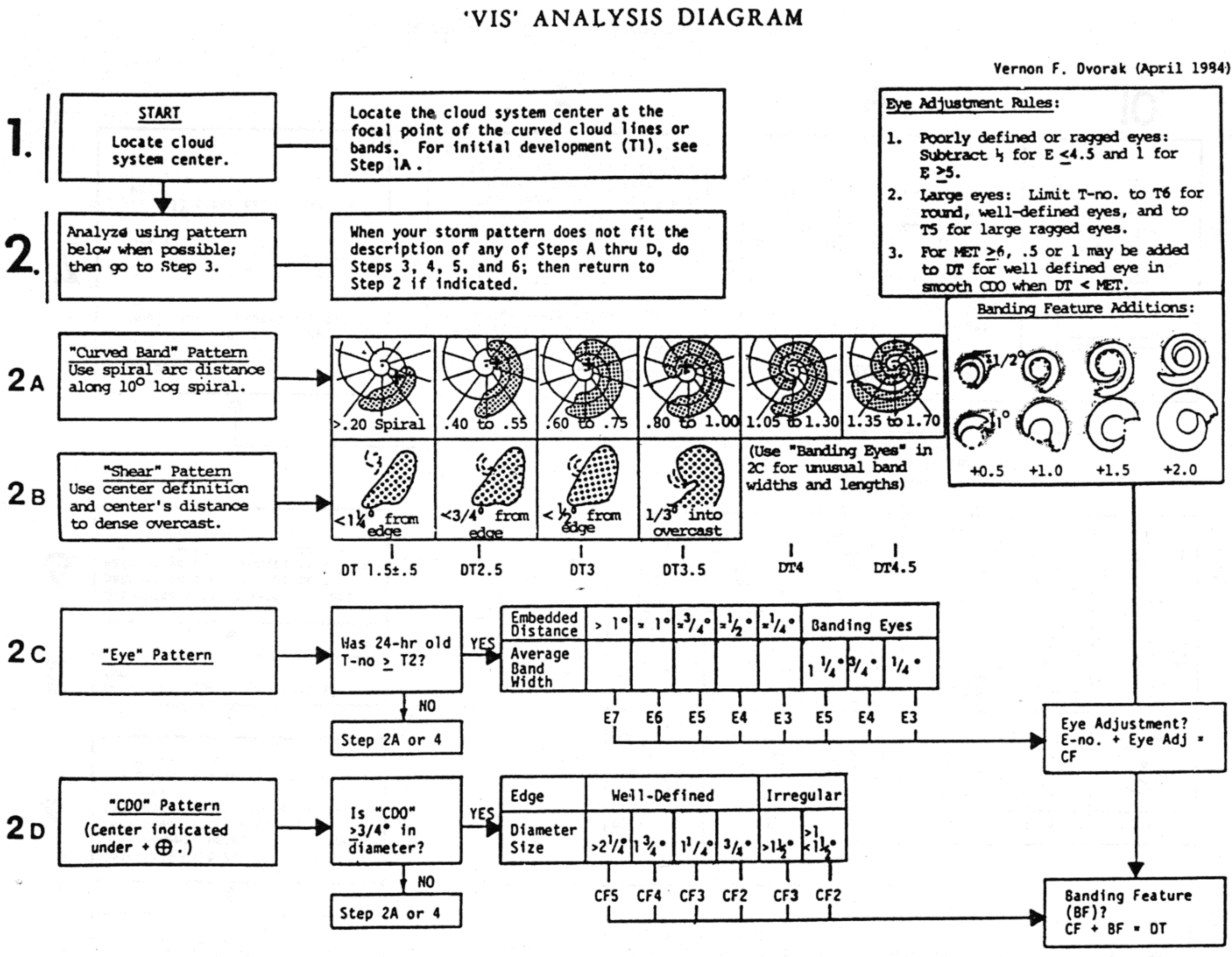
| | 1-minute MSW | | | | NHC/CPHC/JTWC | |
|---|---|---|---|---|---|---|
| CI Number | (kt) | (mph) | (km/ hr) | (m/s) | MSLP (ATL/EPAC) | MSLP (NW Pacific) |
| 1.0 | 25 | 29 | 46 | 13 | | |
| 1.5 | 25 | 29 | 46 | 13 | | |
| 2.0 | 30 | 35 | 56 | 15 | 1009 mb | 1000 mb |
| 2.5 | 35 | 40 | 65 | 18 | 1005 mb | 997 mb |
| 3.0 | 45 | 52 | 83 | 23 | 1000 mb | 991 mb |
| 3.5 | 55 | 63 | 102 | 28 | 994 mb | 984 mb |
| 4.0 | 65 | 75 | 120 | 33 | 987 mb | 976 mb |
| 4.5 | 77 | 89 | 143 | 40 | 979 mb | 966 mb |
| 5.0 | 90 | 104 | 167 | 46 | 970 mb | 954 mb |
| 5.5 | 102 | 117 | 189 | 52 | 960 mb | 941 mb |
| 6.0 | 115 | 132 | 213 | 59 | 948 mb | 927 mb |
| 6.5 | 127 | 146 | 235 | 65 | 935 mb | 914 mb |
| 7.0 | 140 | 161 | 259 | 72 | 921 mb | 898 mb |
| 7.5 | 155 | 178 | 287 | 80 | 906 mb | 879 mb |
| 8.0 | 170 | 196 | 315 | 87 | 890 mb | 858 mb |

**Note: Other warning centers and basins use different pressures and wind averaging periods**

# Dvorak Technique Procedure

**Dvorak (1984) 10 Steps:**

1. Locate center
2. Select cloud pattern and assign Data-T Number (DT)



'VIS' ANALYSIS DIAGRAM

Vernon F. Dvorak (April 1984)

1. START — Locate cloud system center.

Locate the cloud system center at the focal point of 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 A thru D, 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.

(Use "Banding Eyes" in 2C for unusual band widths and lengths)

2C "Eye" Pattern — Has 24-hr old T-no ≥ T2? YES / NO → Step 2A or 4

2D "CDO" Pattern (Center indicated under + ⊕.) — Is "CDO" ≥3/4° in diameter? YES / NO → Step 2A or 4

**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:**

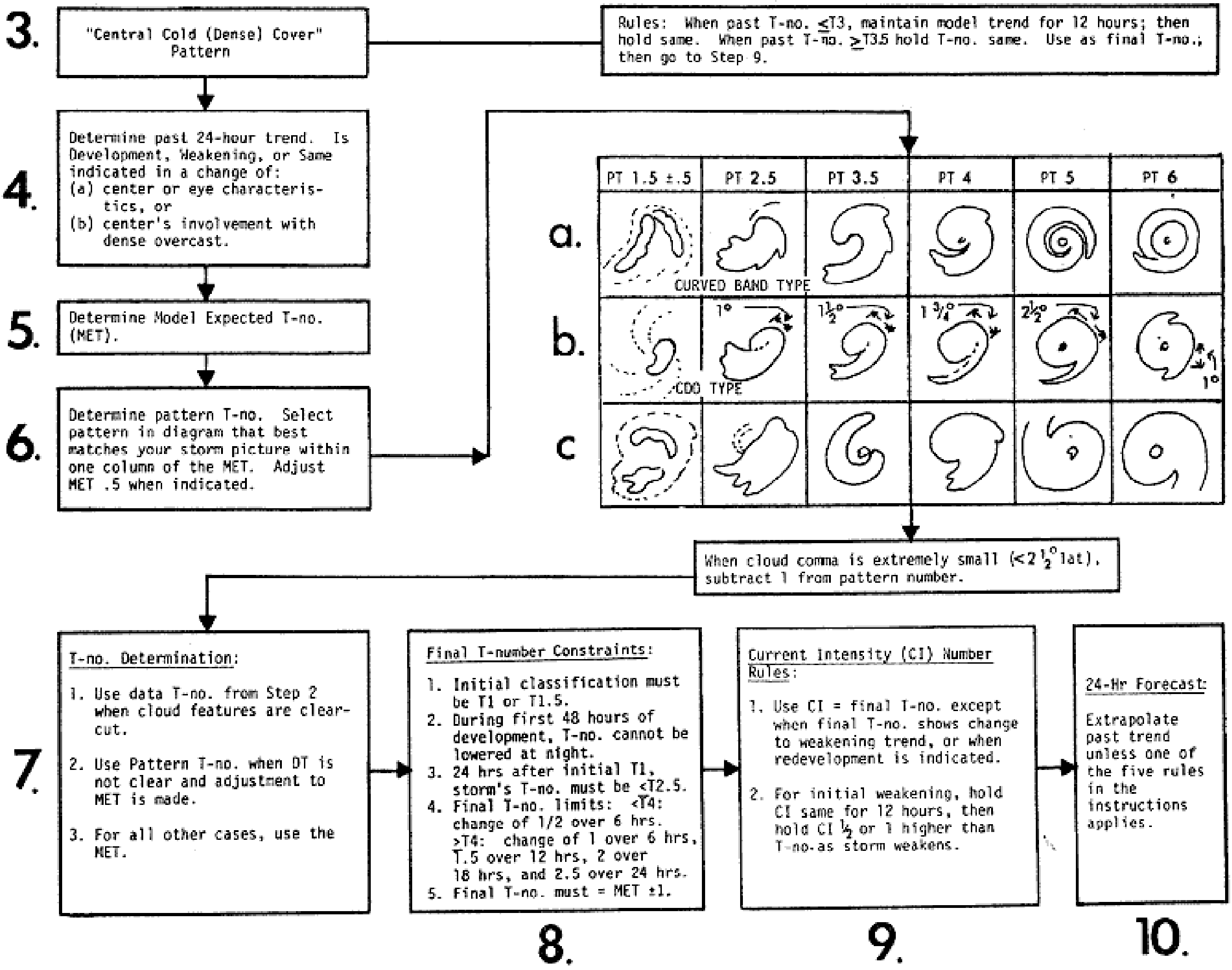
Eye Adjustment? E-no. + Eye Adj = CF

Banding Feature (BF)? CF + BF = DT

# Dvorak Technique Procedure

**Dvorak (1984) 10 Steps:**

3. Central Cold Cover (CCC; if applicable)
4. Analyze 24-h trend
5. Assign Model Expected T-Number (MET)
6. Assign Pattern T-Number (PT/PAT)
7. Use DT, MET, and PT to get Final T-Number (FT)
8. Apply FT constraints
9. Determine Current Intensity (CI)
10. Forecast 24-h Intensity (FI)



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 ($<2\frac{1}{2}^{\circ}$ 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.

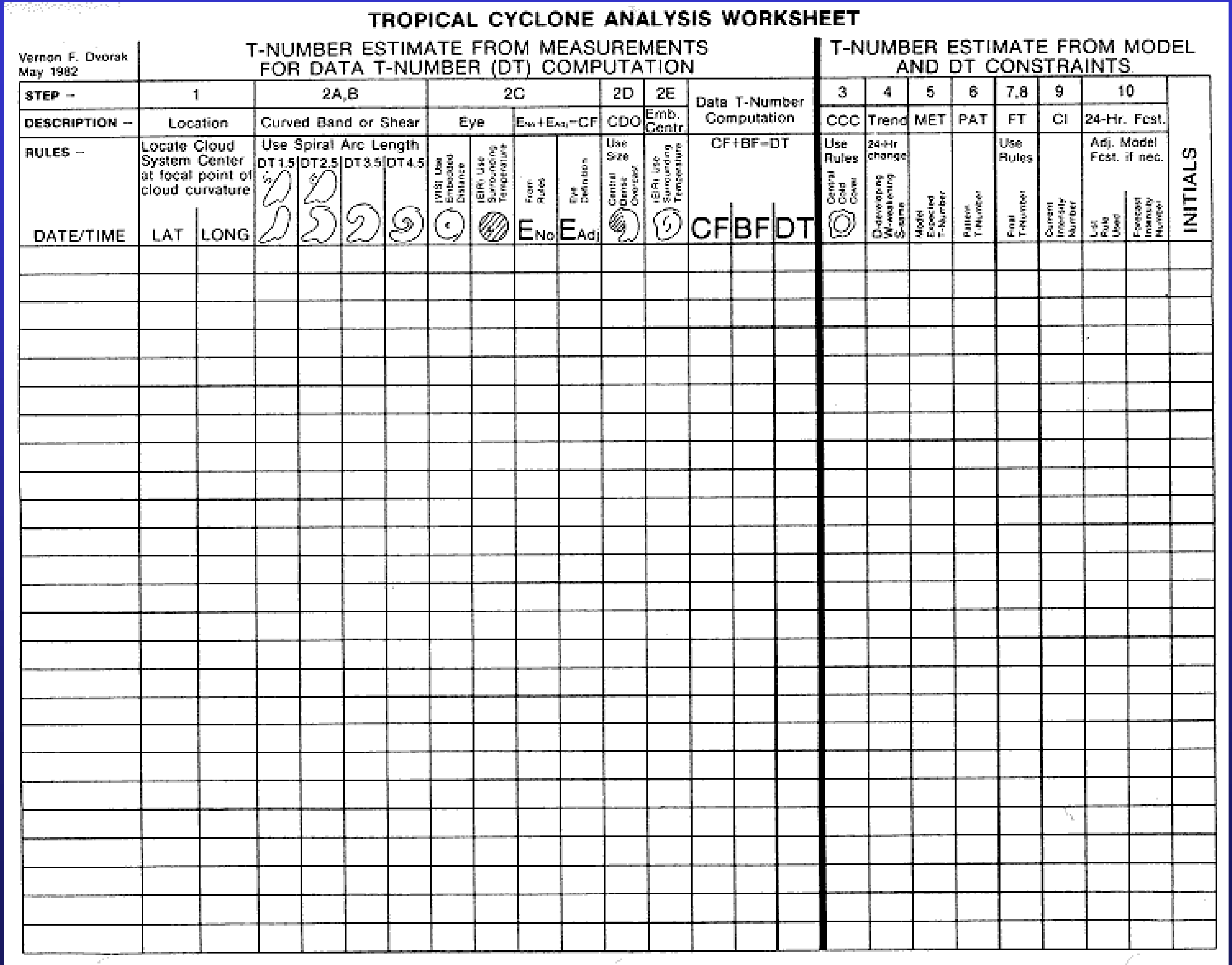
9. Current Intensity (CI) Number Rules:

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.

# Dvorak Technique Worksheet



## TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | INITIALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (IR) Use Surrounding Temperature | From Rules | Eye Definition | Central Dense Overcast | (IR) Use Surrounding Temperature | | | | Central Cold Cover | D-developing W-weakening S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | Last Rule Used | Forecast Intensity Number | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | | | | | | | | |
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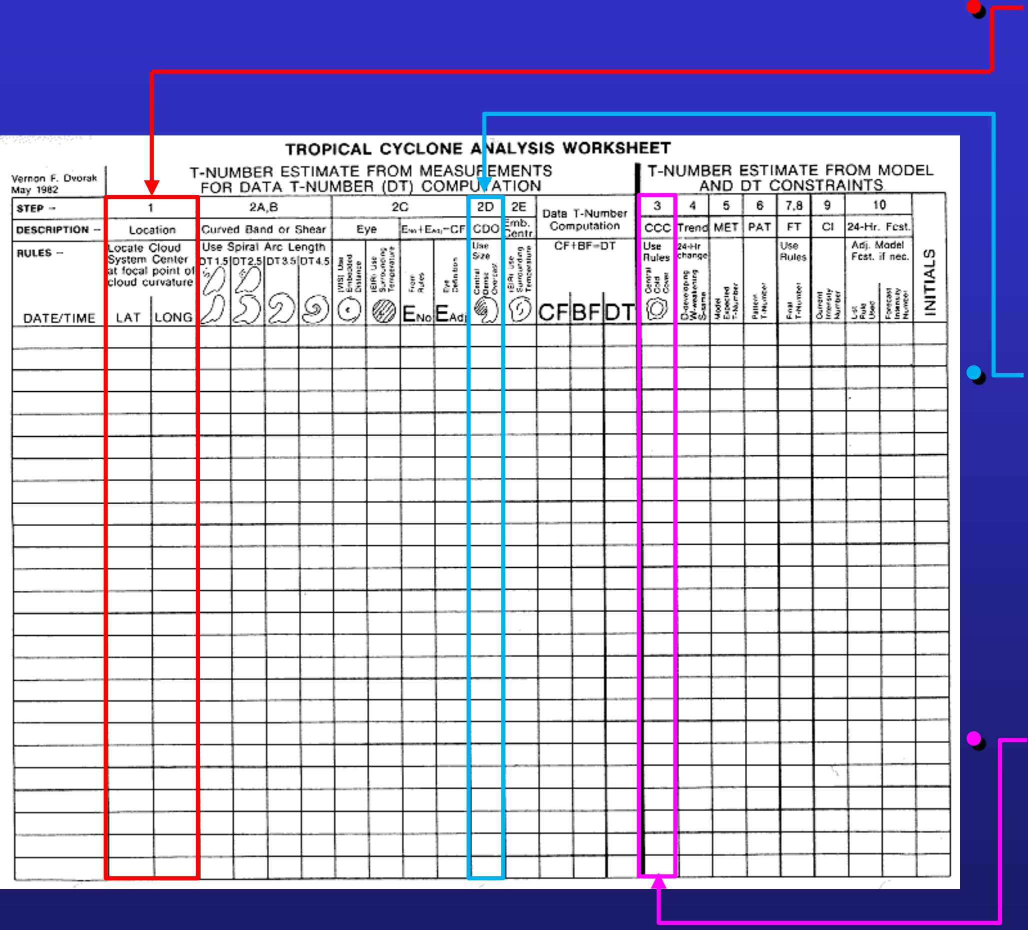
# Dvorak Technique Terms



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

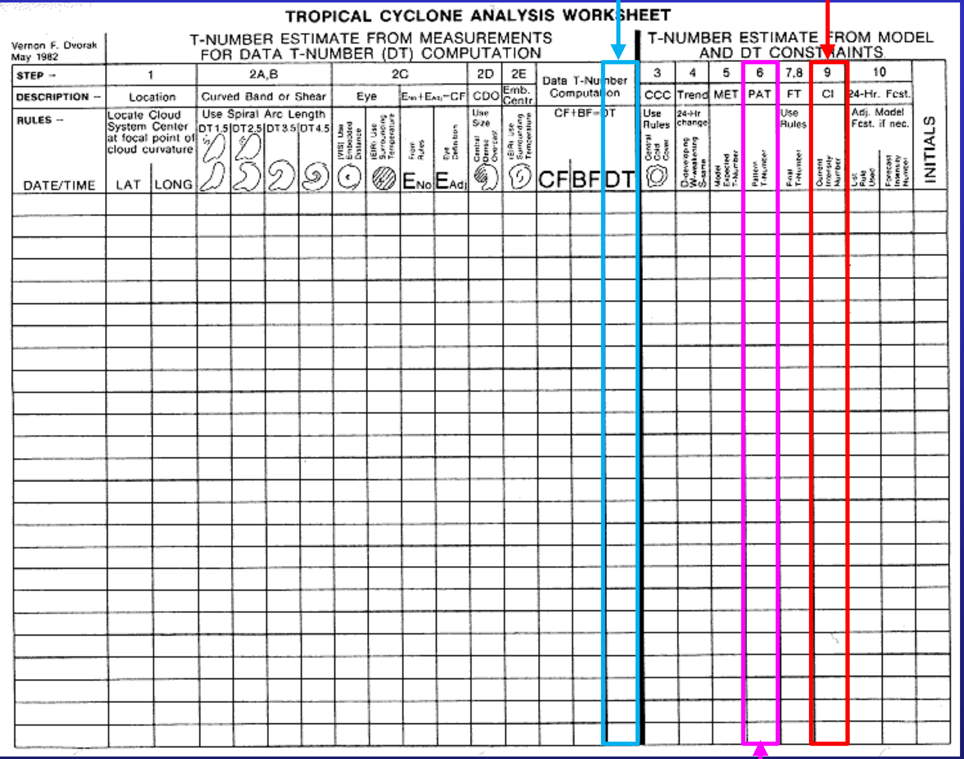
T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | 2A,B | 2C | 2D | 2E | Data T-Number Computation | 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | INITIALS |
| DESCRIPTION → | Location | Curved Band or Shear | Eye<br>$E_{No}+E_{Adj}-CF$ | CDO | Emb. Centr. | | CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | Use Spiral Arc Length<br>DT1.5<br>DT2.5<br>DT3.5<br>DT4.5 | (VIS) Use Embedded Distance<br>(EIR) Use Surrounding Temperature<br>From Rules<br>Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | Use Rules<br>Central Cold Cover | 24-Hr change<br>D-developing W-weakening S-same | Model Expected T-Number | Pattern T-Number | Use Rules<br>Final T-Number | Current Intensity Number | Adj. Model Fcst. if nec.<br>List Rule Used<br>Forecast Intensity Number | |
| DATE/TIME | LAT<br>LONG | | $E_{No}$<br>$E_{Adj}$ | | | CF<br>BF<br>DT | | | | | | | | |

- ***CSC*** **- <u>C</u>loud <u>S</u>ystem <u>C</u>enter - The center of the disturbance or cyclone. It is usually defined by an eye, a low level circulation center, or by other cloud features.**
- ***CDO*** **- <u>C</u>entral <u>D</u>ense <u>O</u>vercast - A dense solid-looking mass of clouds covering the CSC, often lying within the curve of the cyclone's curved cloud band.**
- ***CCC*** **- <u>C</u>entral <u>C</u>old <u>C</u>over - A large cold or dense overcast covering the CSC that lacks structure and obscures the cyclone center.**

# Dvorak Technique Terms



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May 1982

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T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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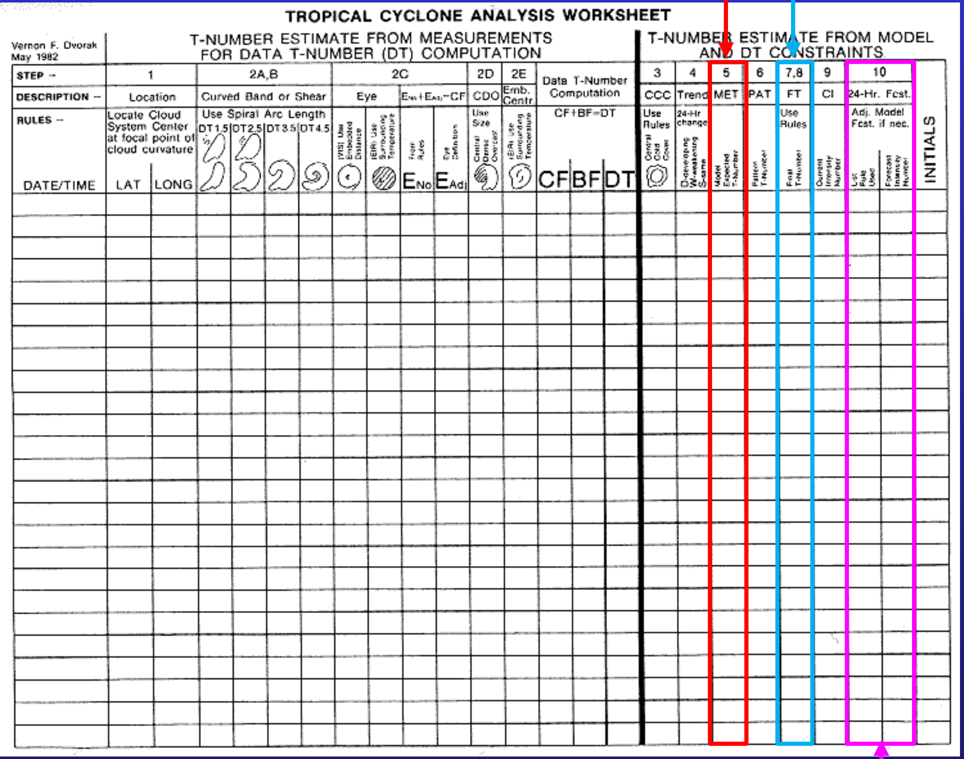
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | | | | | | | | |

- *CI Number* - Current Intensity number - The final output of the Dvorak technique and the estimated intensity of the cyclone.
- *DT Number* - Data-T number - The estimated intensity of the cyclone based on the convective cloud pattern.
- *PT or PAT Number* - Pattern-T number - The intensity estimate from comparing the cyclone cloud pattern to predetermined patterns.

# Dvorak Technique Terms



TROPICAL CYCLONE ANALYSIS WORKSHEET

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vernon F. Dvorak<br>May 1982 | T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION | | | | | | | | | | | | | | | T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS | | | | | | | | |
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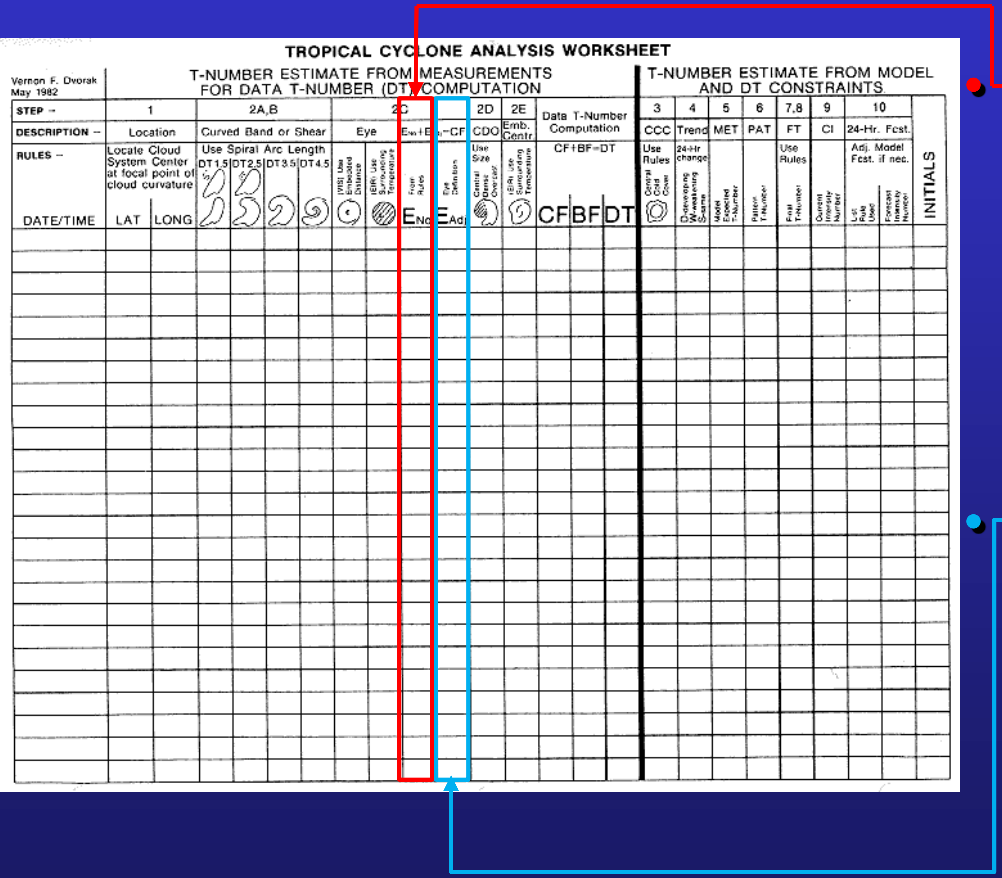
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | Central Dense Overcast | | | | | Central Cold Cover | D=developing<br>W=weakening<br>S=same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | | | | | | | | |

- *MET Number* - Model Expected-T number - The intensity estimate from the 24 hr old FT number and a determined intensity trend.
- *FT Number* - Final-T number - The intensity estimate for a given time selected from the DT, PT, or MET numbers. It is used with a set of rules to determine the CI number for this time and the MET number 24 hours later.
- *FI Number* - Forecast Intensity number - 24 hr intensity forecast based on the CI and observed signals in the cyclone cloud pattern and the environment.

# Dvorak Technique Terms



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Vernon F. Dvorak
May 1982

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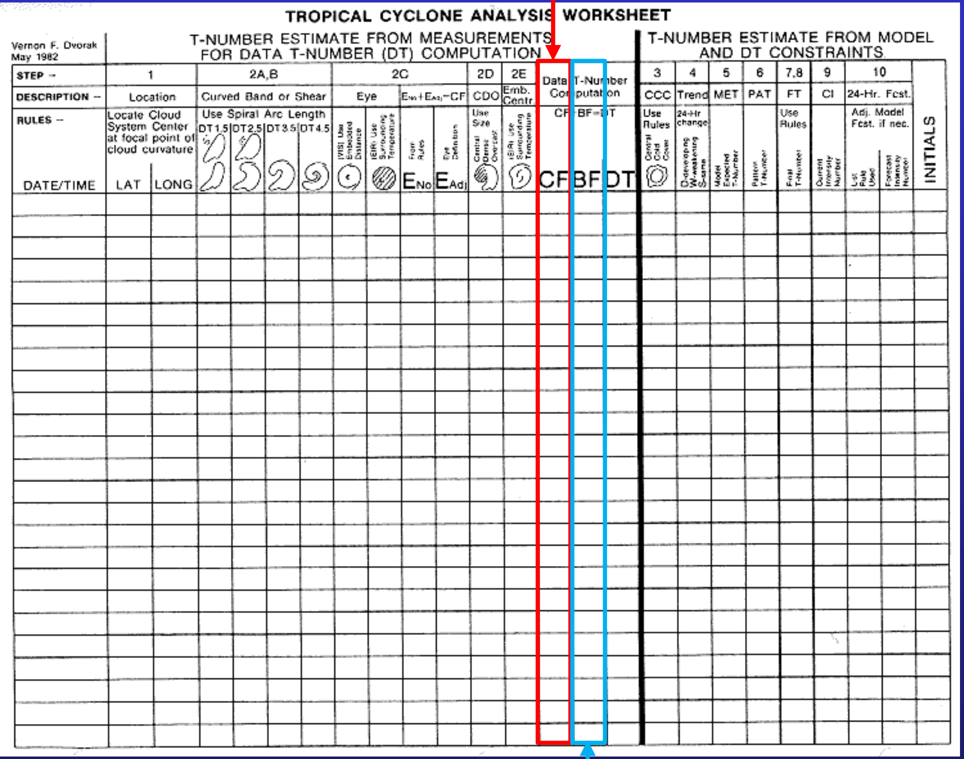
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | | CDO | Emb. Centr. | | | | CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | INITIALS |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | | Central Dense Overcast | (EIR) Use Surrounding Temperature | | | | Central Cold Cover | D-developing W-weakening S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | | CF | BF | DT | | | | | | | | | |

- *Eye Number* - Part 1 of the intensity estimate for an eye pattern based on surrounding cloud top temperatures (IR) or embedded distance in a CDO (VIS).
- *Eye Adjustment* - Part 2 of the intensity estimate for an eye pattern based on eye temperature (IR) or eye size and clarity (VIS).

# Dvorak Technique Terms



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

| T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION | | | | | | | | T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | 2A,B | 2C | | 2D | 2E | | 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | |
| DESCRIPTION – | Location | Curved Band or Shear | Eye | $E_{No}+E_{Adj}-CF$ | CDO | Emb. Centr. | Data T-Number Computation | CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | INITIALS |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | Use Spiral Arc Length<br>DT1.5 DT2.5 DT3.5 DT4.5 | (VIS) Use Embedded Distance<br>(EIR) Use Surrounding Temperature | From Rules<br>Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | Use Rules<br>Central Cold Cover | 24-Hr change<br>D-developing W-weakening S-same | Model Expected T-Number | Pattern T-Number | Use Rules<br>Final T-Number | Current Intensity Number | Adj. Model Fcst. if nec.<br>List Rule Used<br>Forecast Intensity Number | |
| DATE/TIME | LAT<br>LONG | | | $E_{No}$<br>$E_{Adj}$ | | | CF<br>BF<br>DT | | | | | | | | |

- ***CF Number*** - <u>C</u>entral <u>F</u>eature number - The part of the intensity estimate based on the central features of a cyclone. This number is produced by the eye, CDO, and embedded center patterns.
- ***BF Number*** - <u>B</u>anding <u>F</u>eature number - The part of the intensity estimate based on the banding surrounding central features of a cyclone. This number can be used with the eye, CDO, and embedded center patterns.

# Dvorak Steps 1 and 2

1.

**START**
Locate cloud system center
(Center fix)

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

1A.

A T1 Classification can first be given upon meeting three criteria involving the existence and persistence of the CSC and associated convection

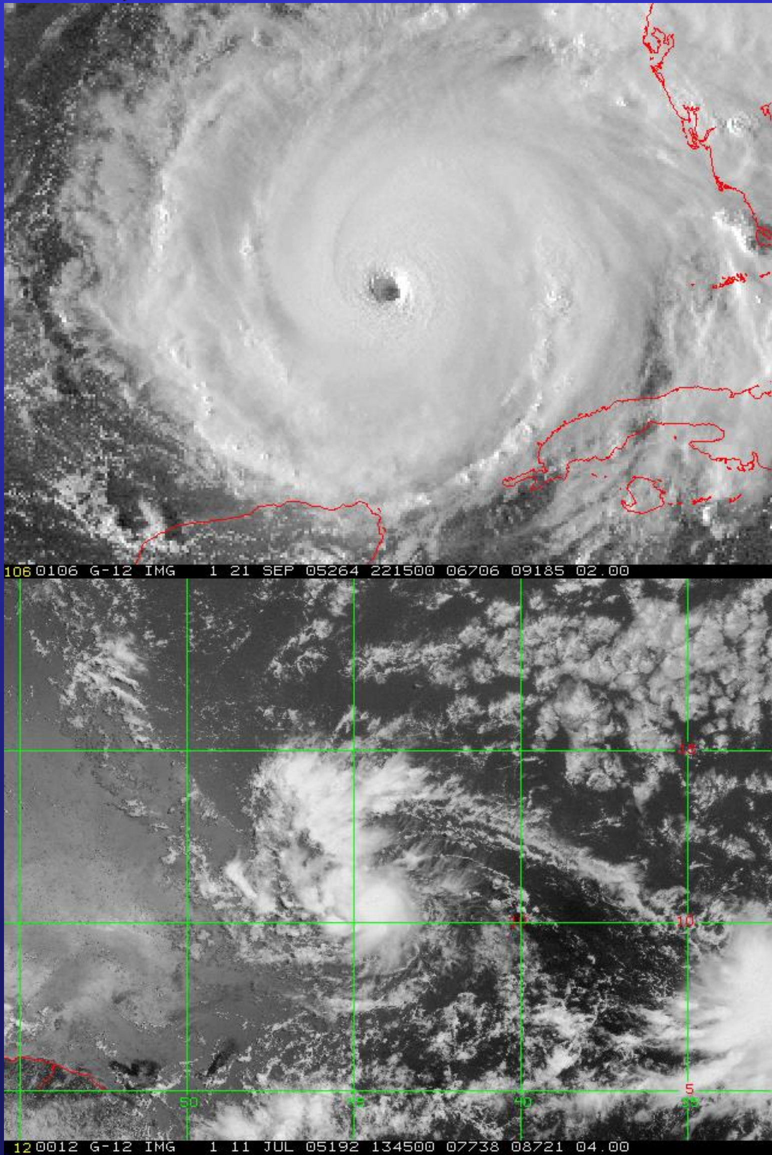
2.

**CLOUD PATTERN MEASUREMENT**
Analyze using cloud pattern
below when possible;
then goto Step 3

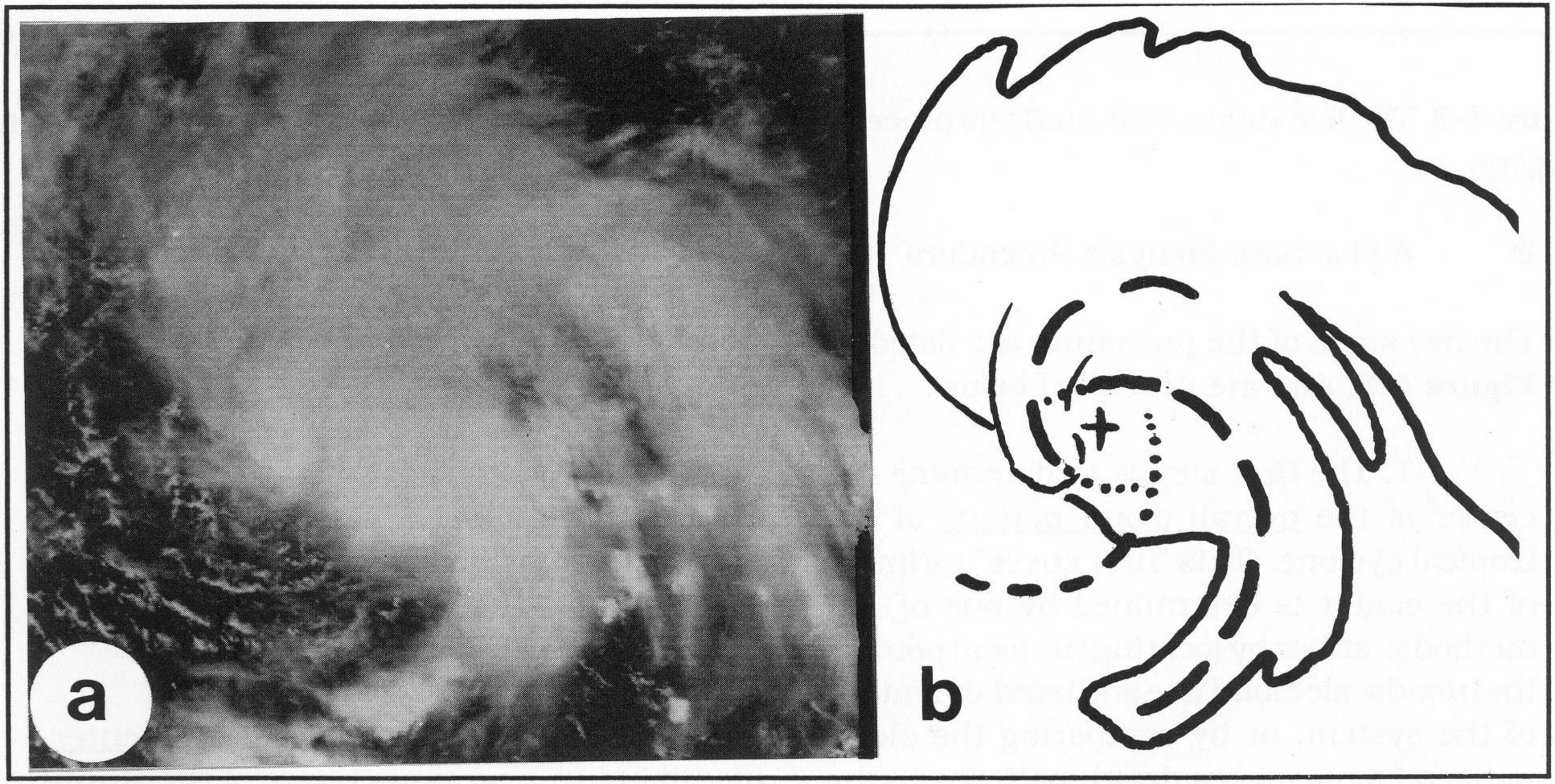
When the storm cloud pattern does not fit any of those in Steps 2A-2D, perform Steps 3, 4, 5, and 6; then return to Step 2 if indicated

# Step 1 - Locate the Cloud System Center (CSC)

- **Locate the overall pattern center**
- **Look for small scale features**
- **Compare center location with forecast**
- **Compare center with previous pattern center**
- **Make final location adjustments**
- **Looking for lowest possible center in terms of altitude (Surface center if possible)**

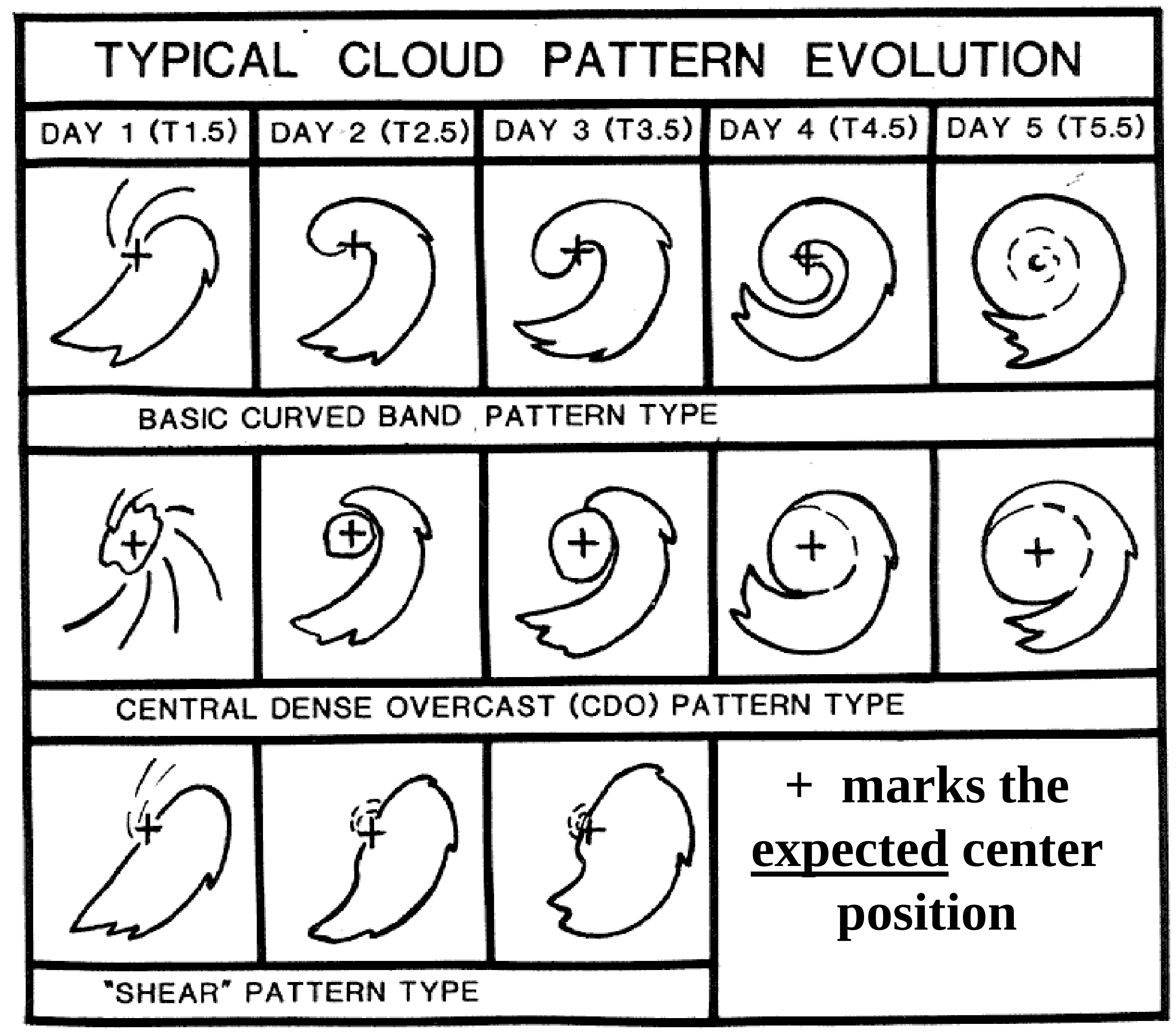


# Step 1 – Locate the Cloud System Center (CSC)



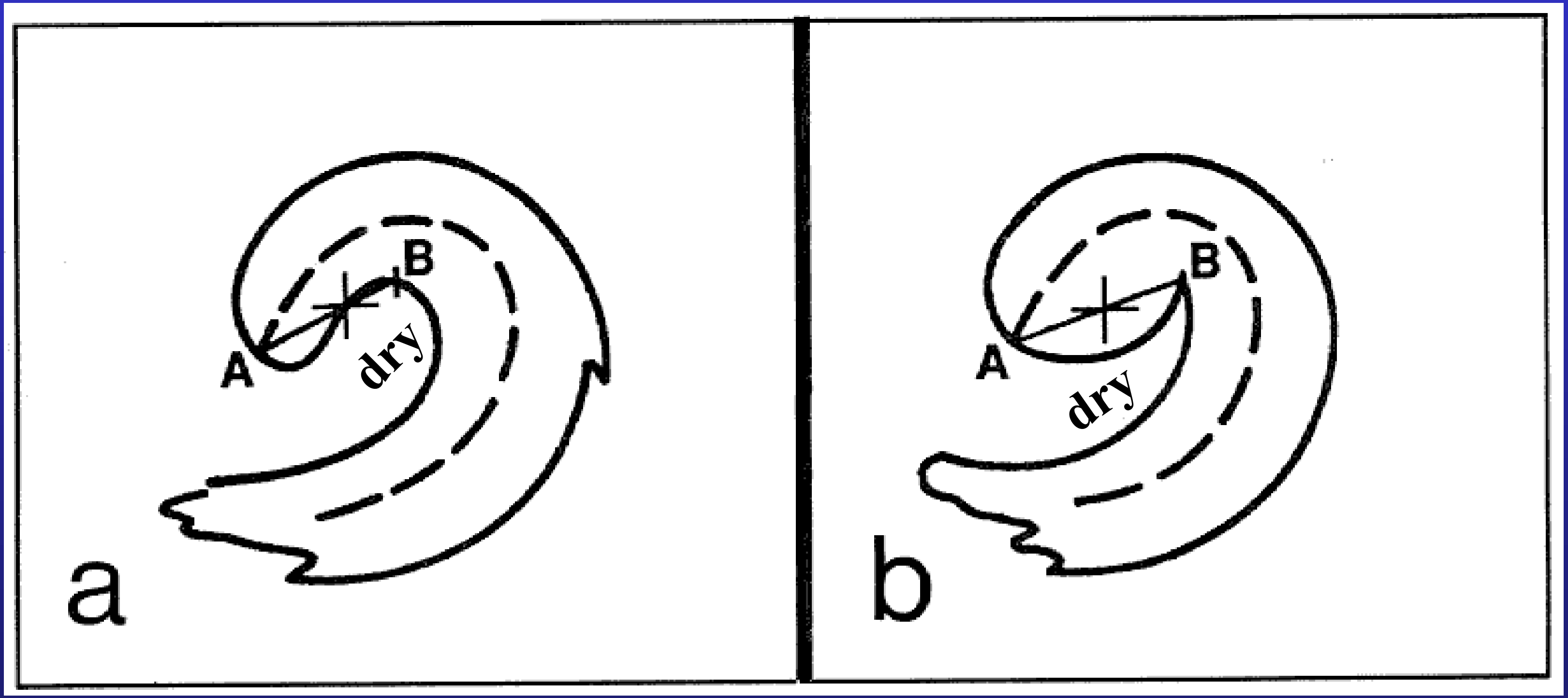
**In this image the CSC is the focal point of curved cloud lines**

# Expected CSC Positions



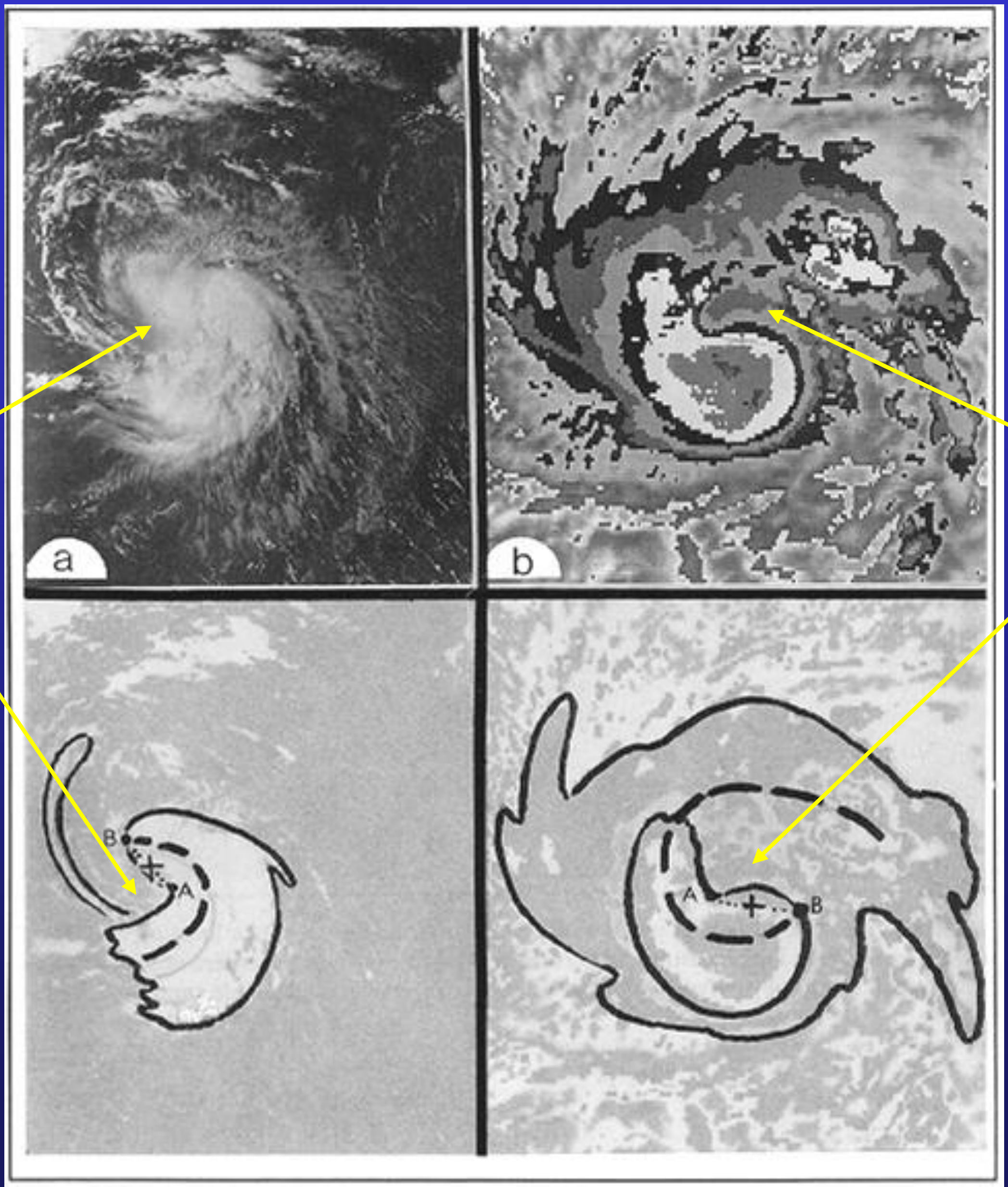
\+ marks the <u>expected</u> center position

# Expected CSC Positions for Curved Band Patterns (Wedge Method)



**The expected center position is halfway between the end of the curved band (A) and the end of the associated dry slot or cloud minimum wedge (B).**

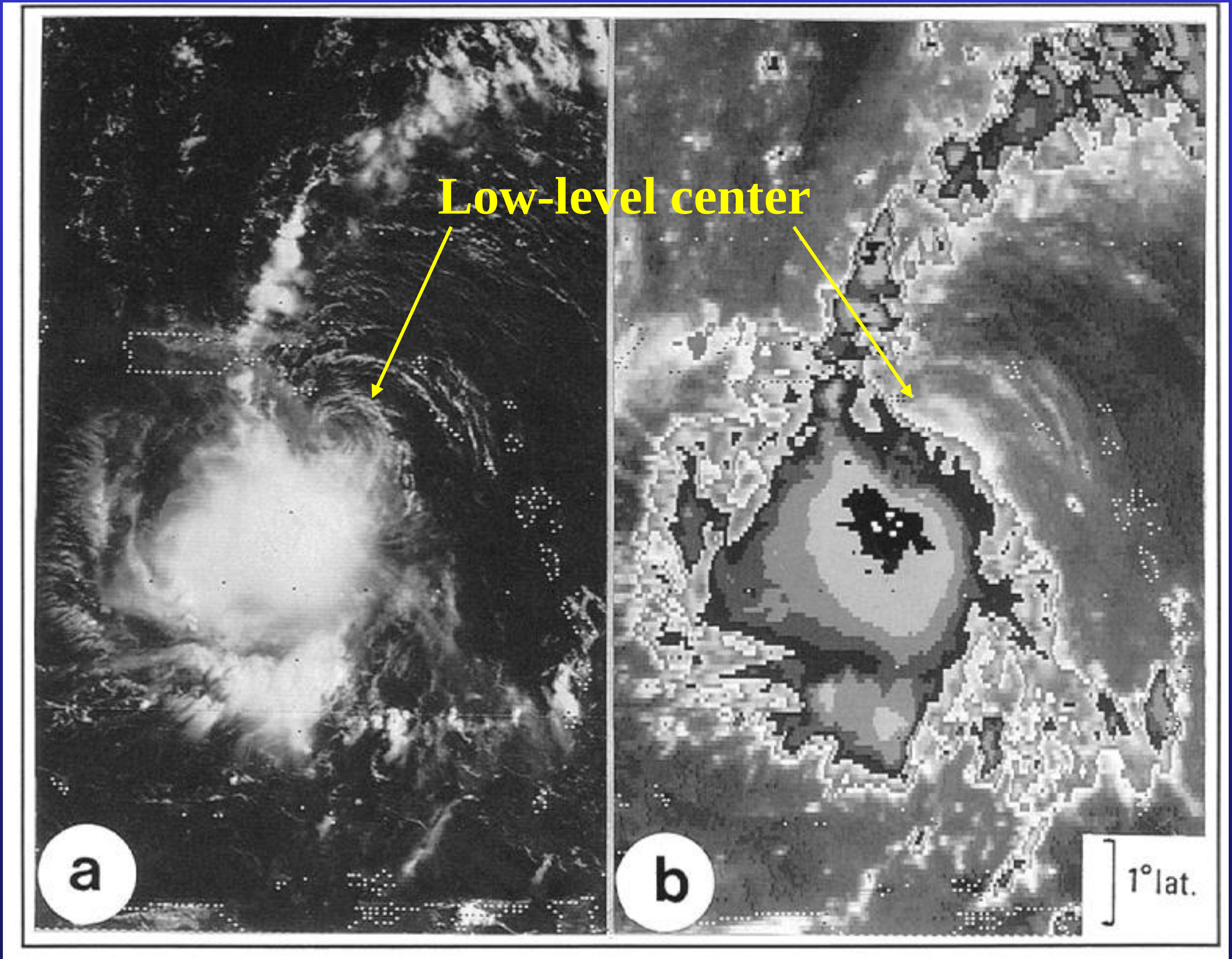
# CSC Curved Band Examples



Dry slot

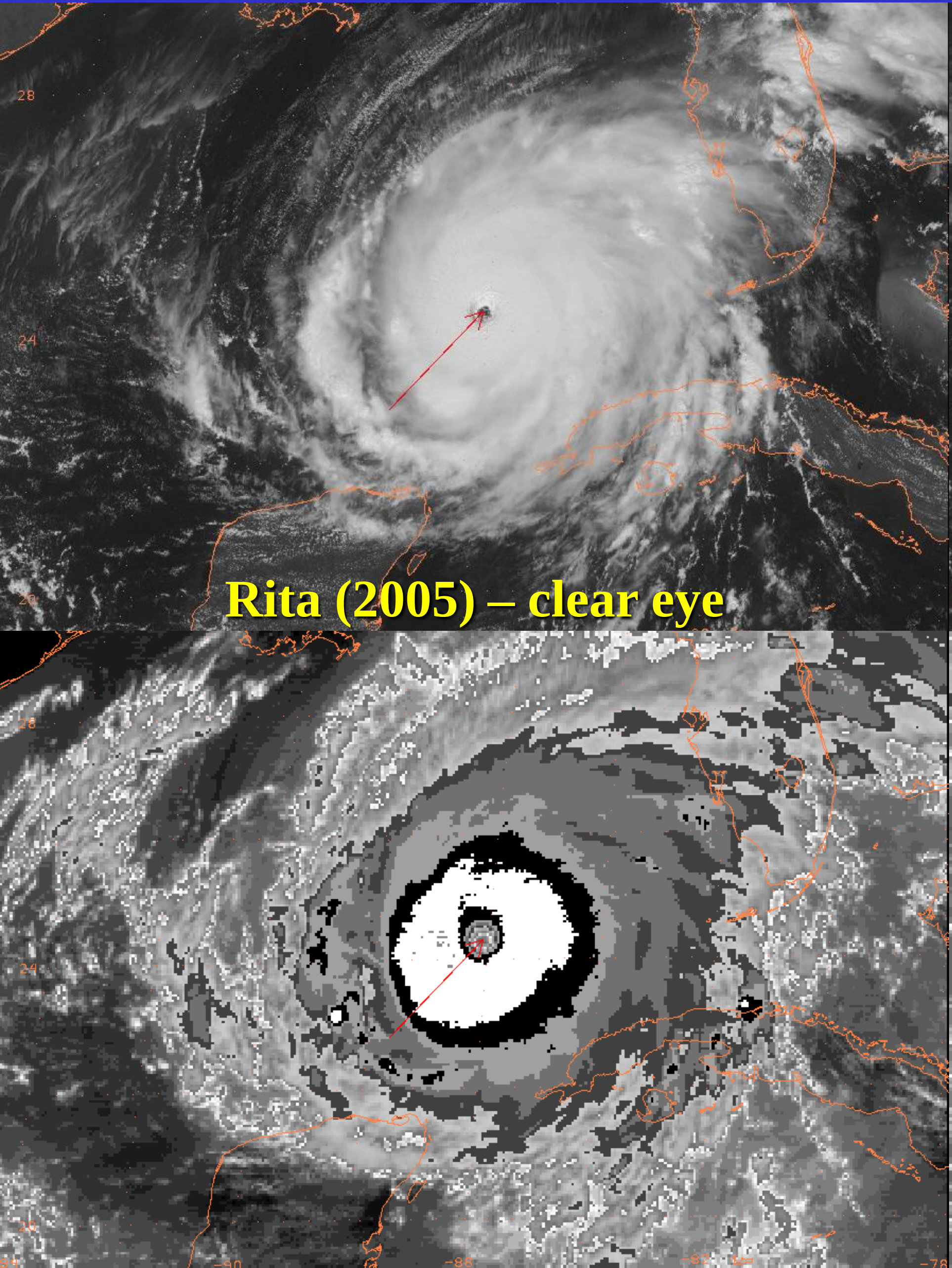
Dry slot

# CSC Shear Pattern Example

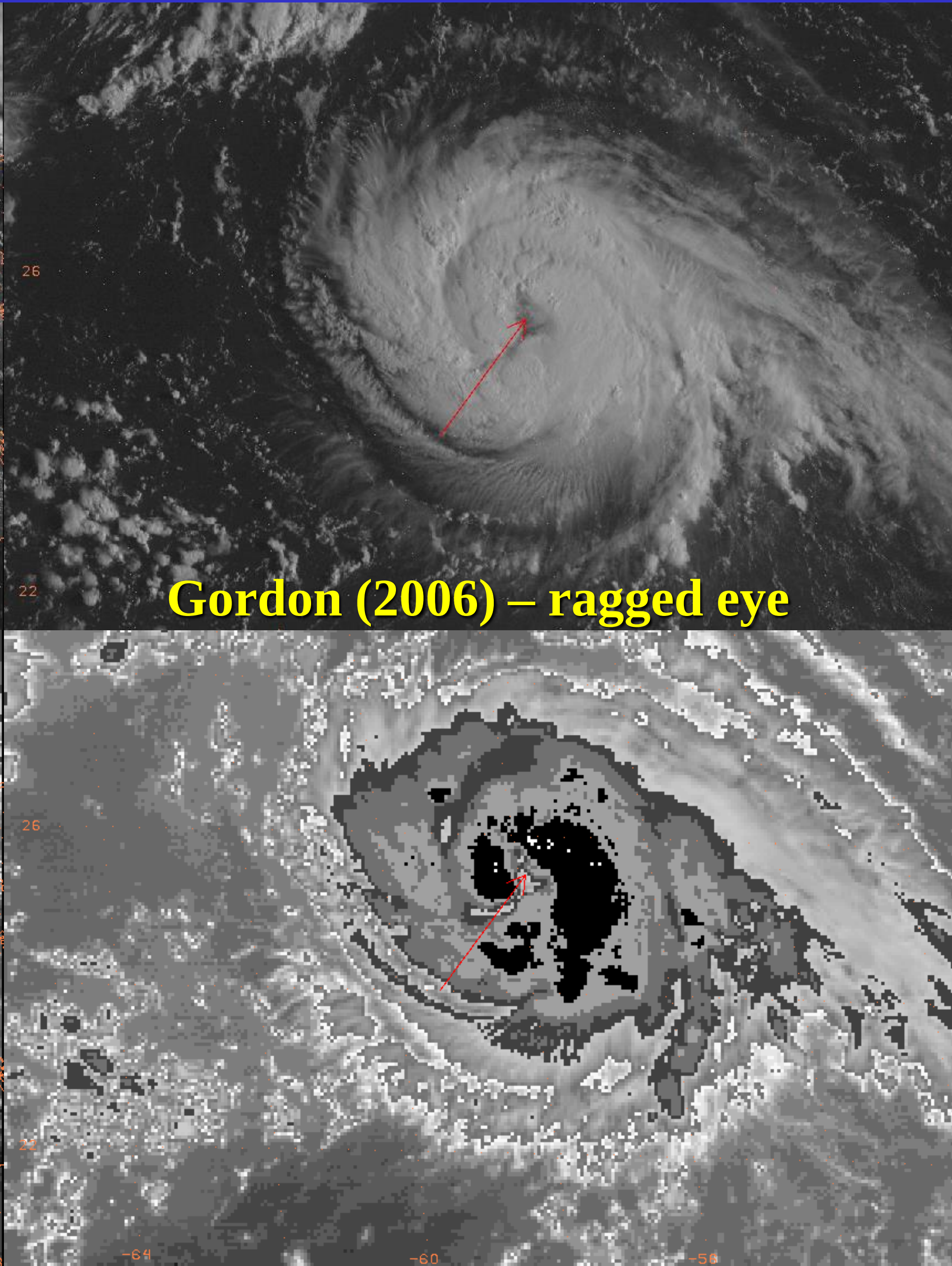


Good first guess position is the upshear side of the strongest convection

# CSC Eye Pattern Examples

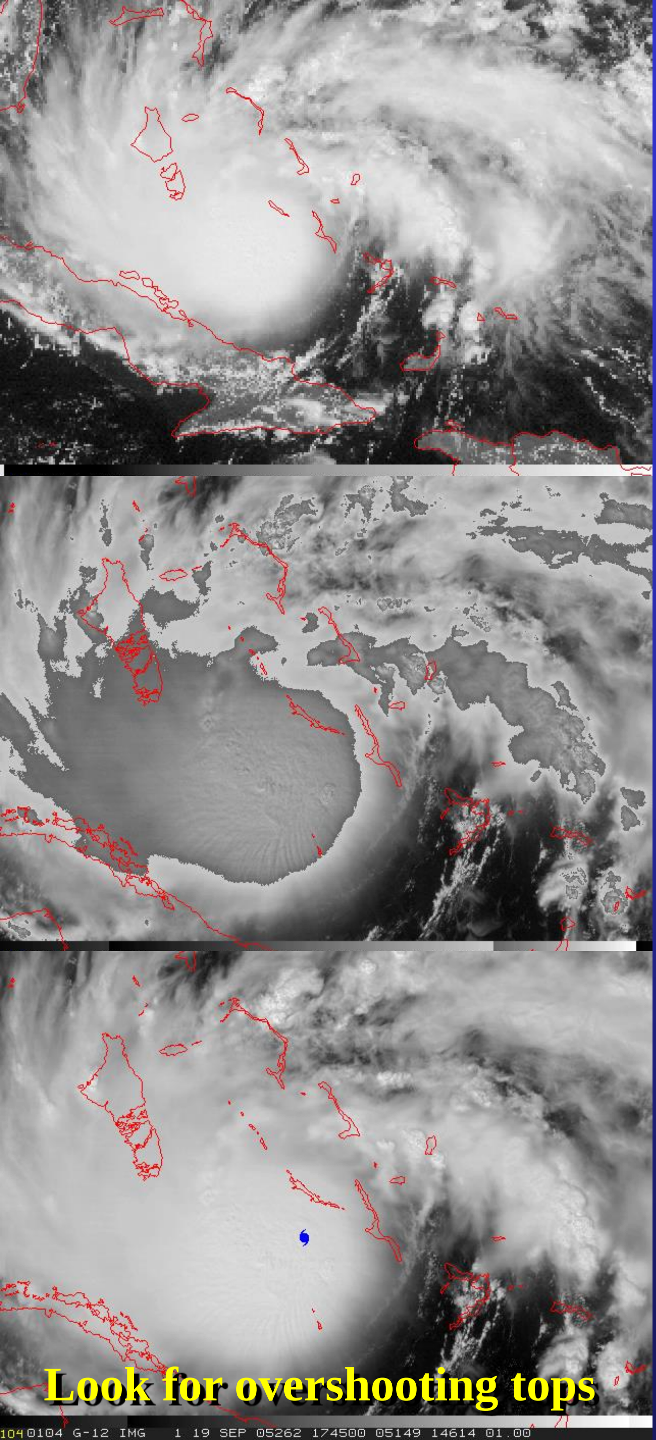


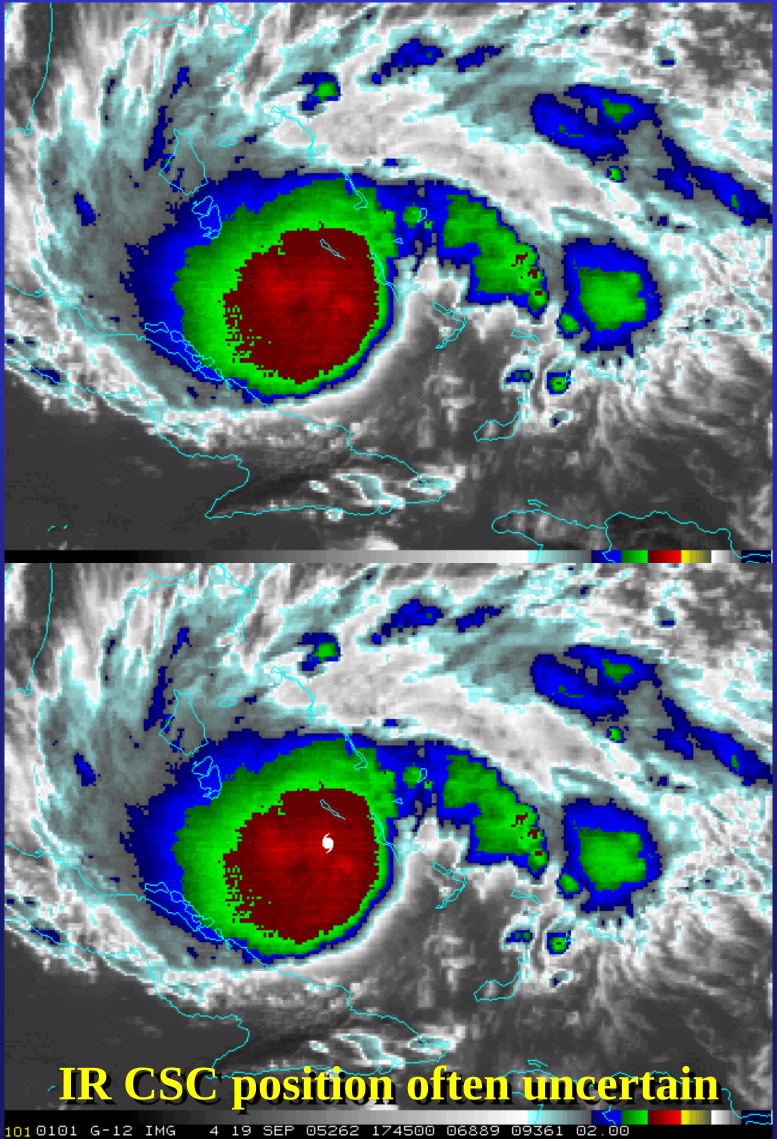
Rita (2005) – clear eye



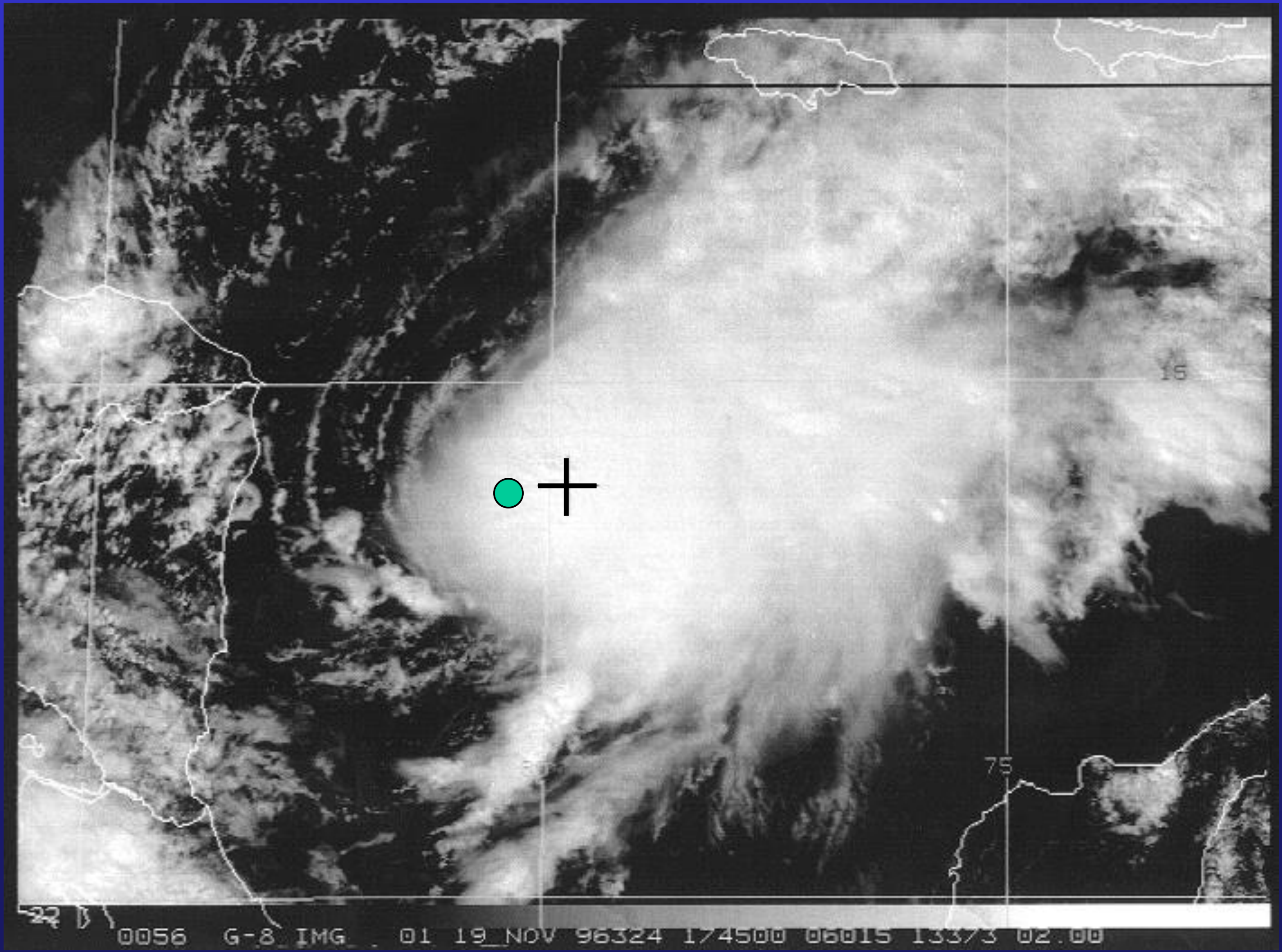
Gordon (2006) – ragged eye

# CDO/Embedded Center Pattern CSC Examples


Look for overshooting tops


IR CSC position often uncertain

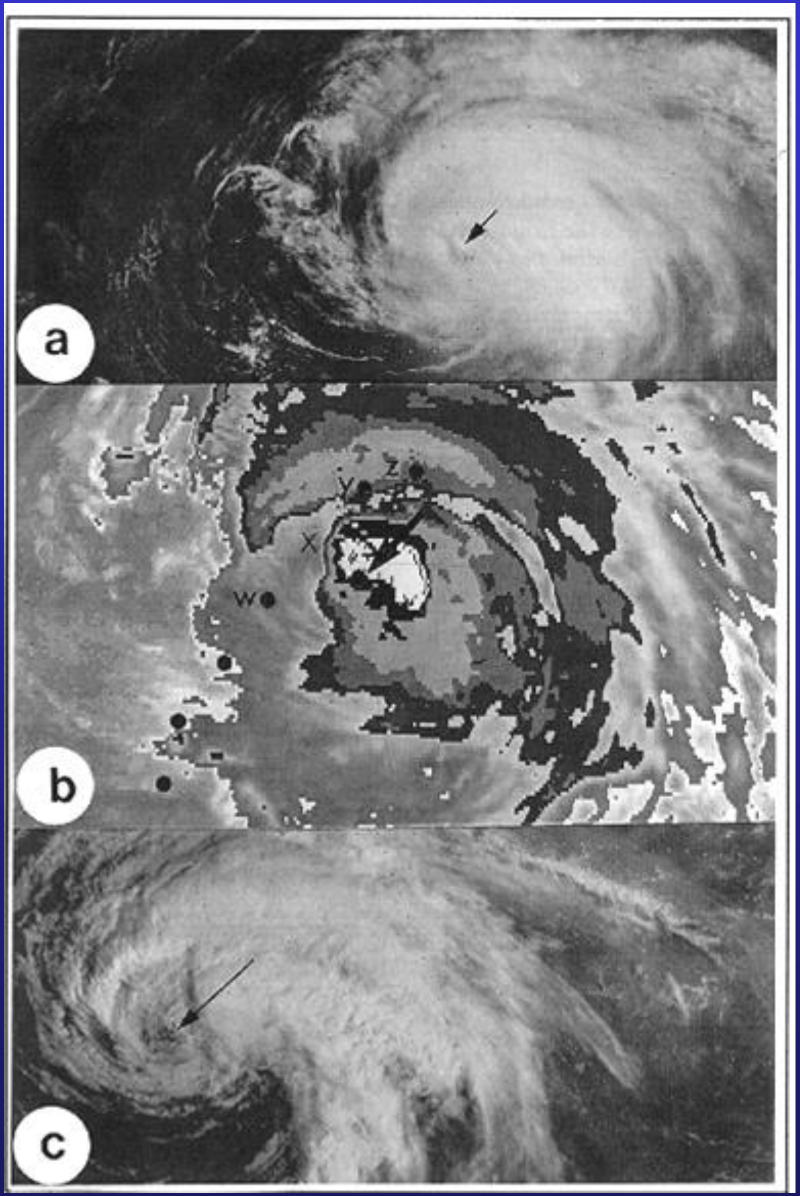
# CSC Location Error - Didn’t Follow the Low Clouds



Marco (1996): A sheared and tilted system!

# Potential Error - Shear Surprise

The previous day

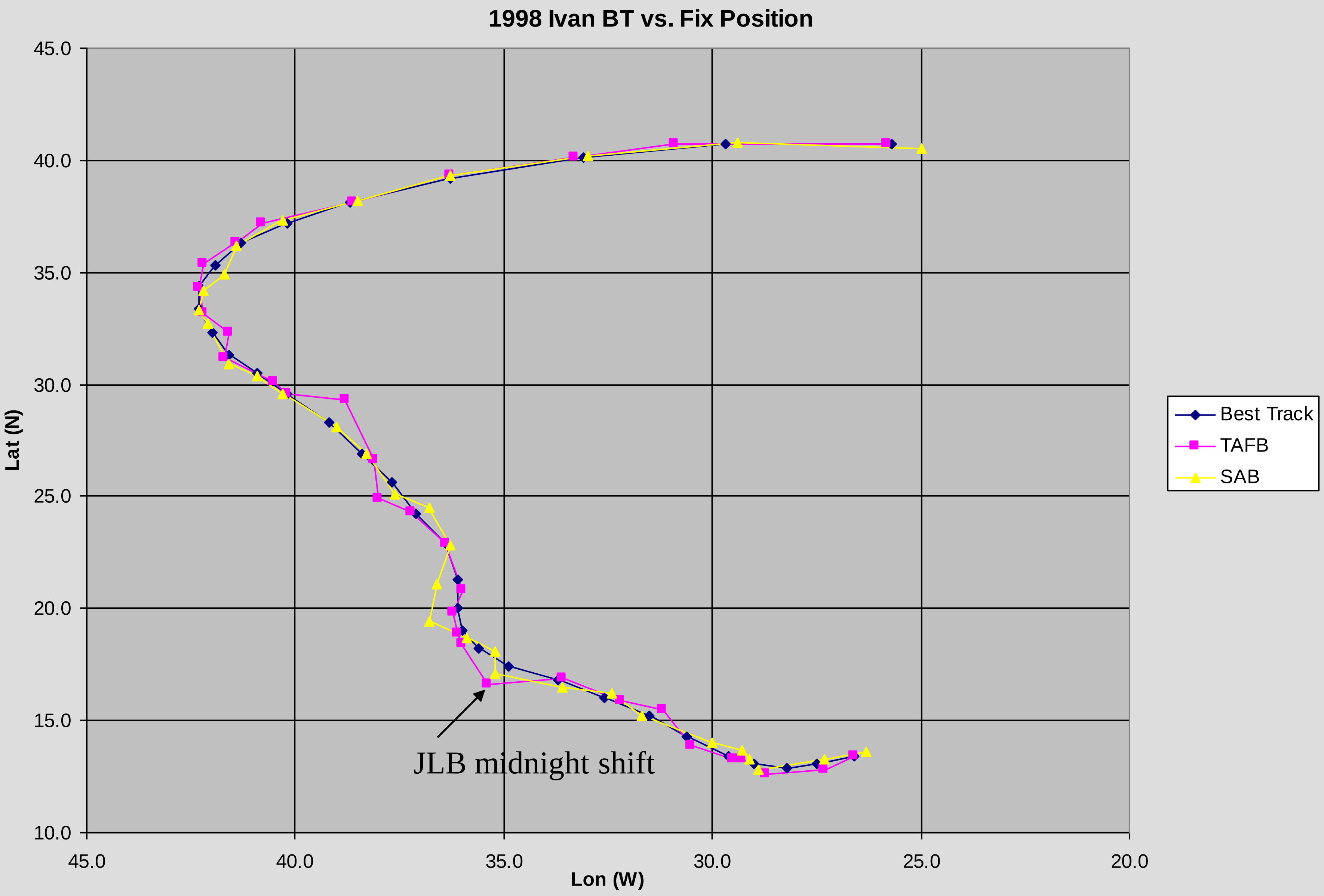


Overnight

Surprise!

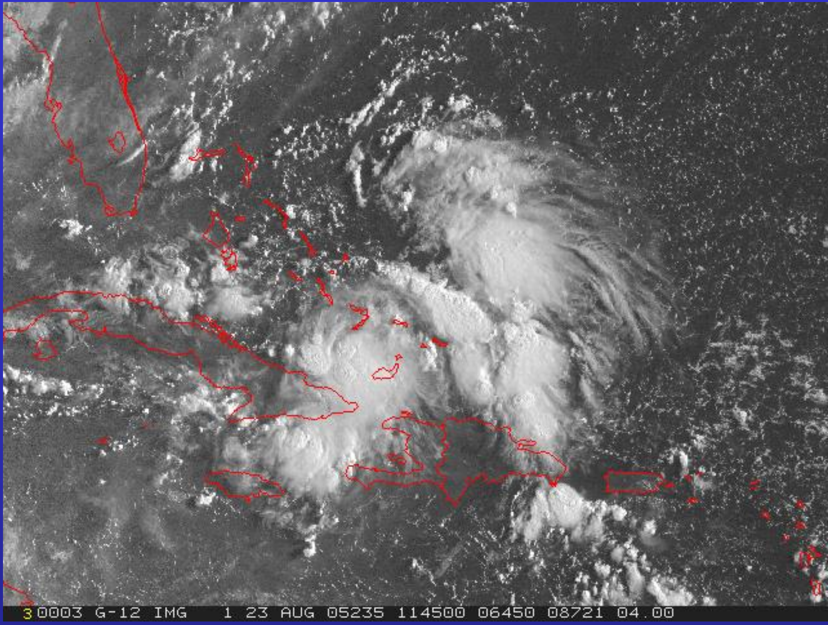
Hurricane Harvey (1981)

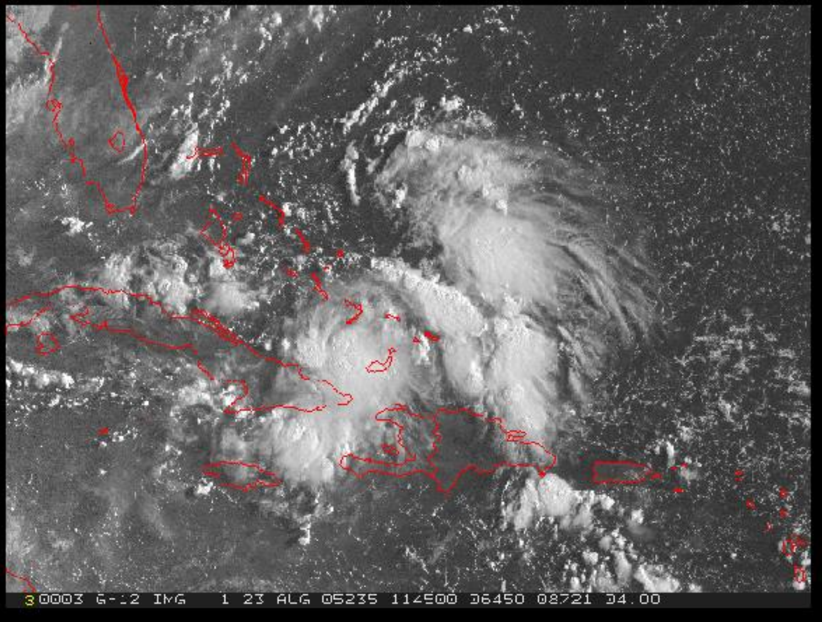
# CSC Error - Deviated From Forecast



# Animated Imagery

- The technique center finding principles were designed for single images and not animation.
- Animation can show the circulation associated with a tropical cyclone or disturbance and make center fixing easier
- Motions of high level clouds can complicate center fixing, especially when using IR imagery or if the system is tilted
- Use of animation does not guarantee a correct center location!





# Dvorak Confidence Codes

## Location Confidence (LCN)

| LCN | Definition |
|---|---|
| 1 | Well-defined eye |
| 2 | Well-defined eye with uncertain picture navigation |
| 3 | Well-defined circulation center |
| 4 | Well-defined circulation center with uncertain picture navigation |
| 5 | Poorly-defined circulation center |
| 6 | Poorly-defined circulation center with uncertain picture navigation |

## Intensity Confidence (ICN)

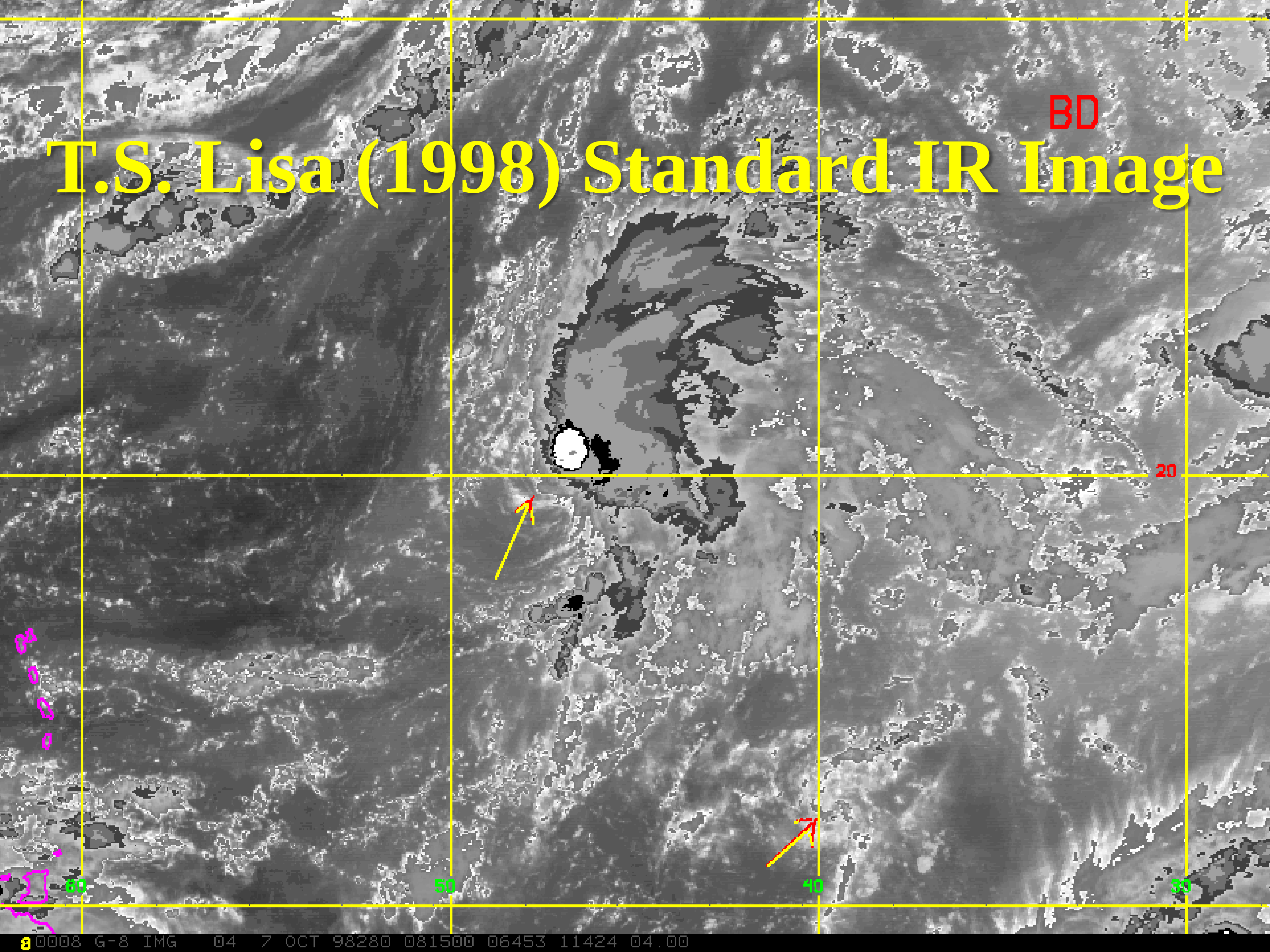
| ICN | Definition |
|---|---|
| 1 | Good confidence in T# |
| 2 | May vary T# up or down by 1/2 |
| 3 | May vary T# up or down by 1 |

# Cloud System Center Finding Exercise!

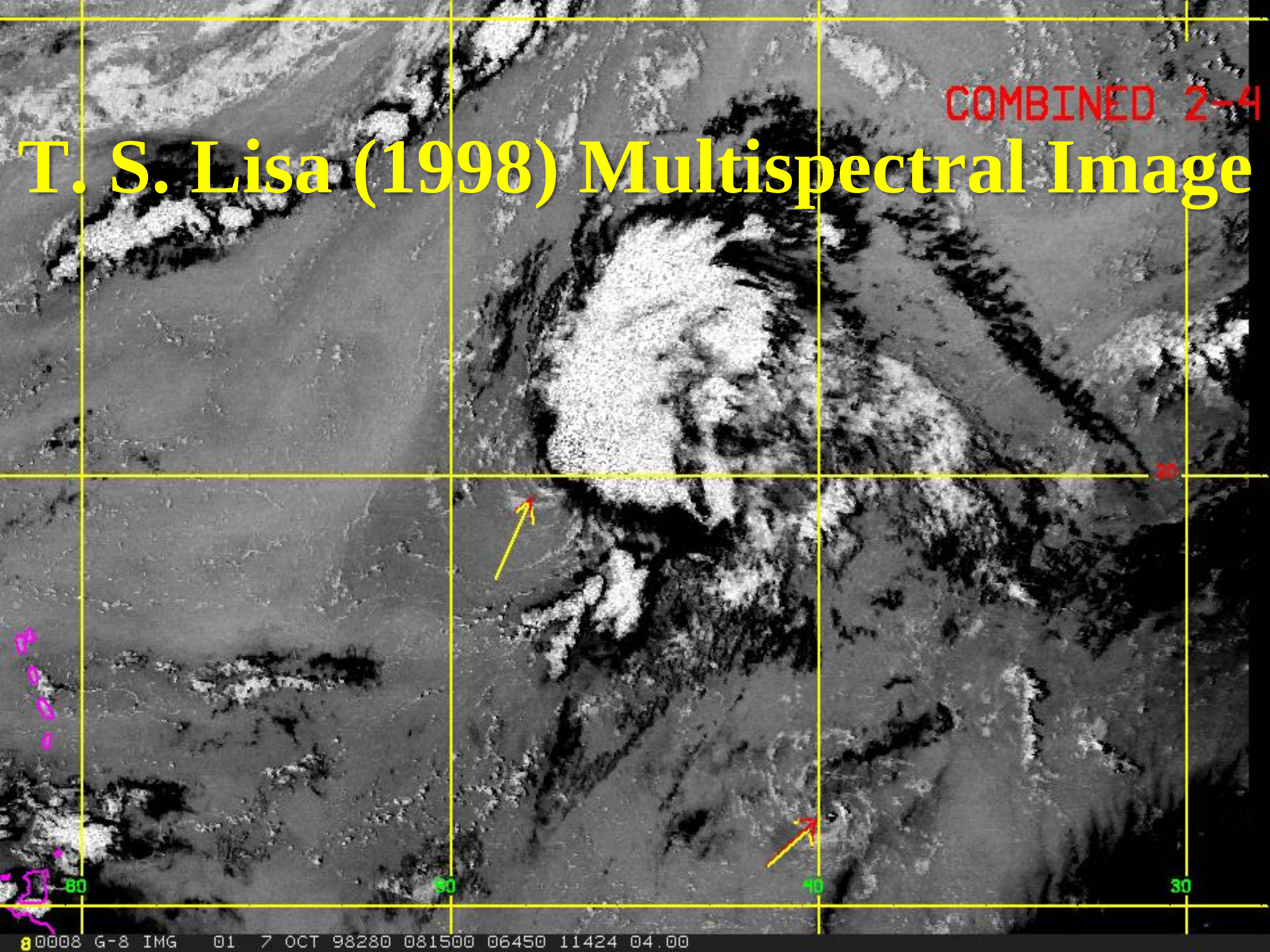
# Notes on Step 1

- Other types of imagery (including microwave) and enhancements may be used in finding the CSC
- The CSC of a weak system is not always a closed circulation center
- In a system with multiple centers, use a mean center position between the centers
- It’s hard to analyze the intensity if you don’t know where the cyclone is!

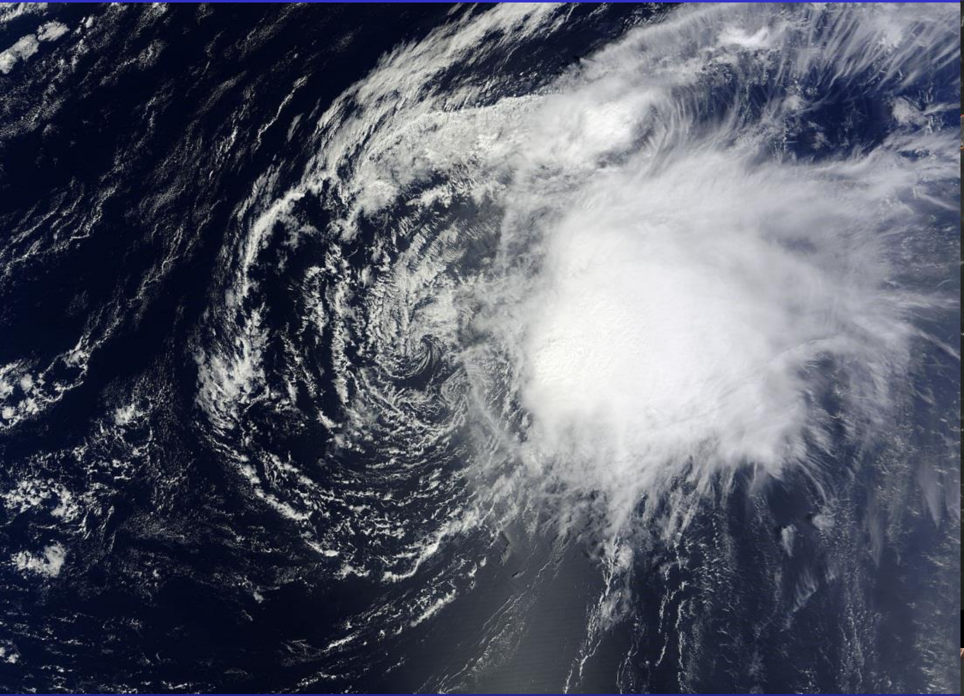
# T.S. Lisa (1998) Standard IR Image



# T. S. Lisa (1998) Multispectral Image



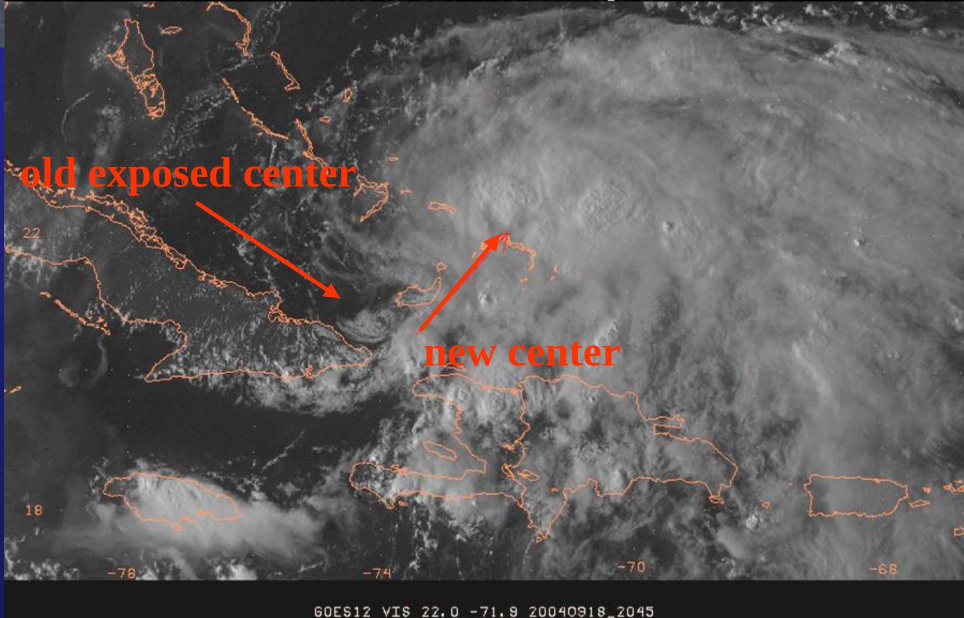
# Cyclones with Multiple Centers



**Oscar (2012) – Multiple swirls present west of the convective mass – need to use a mean center**

**Jeanne (2004) - New center forms northeast of the old exposed center (images are 3 hr apart)**

exposed center



old exposed center

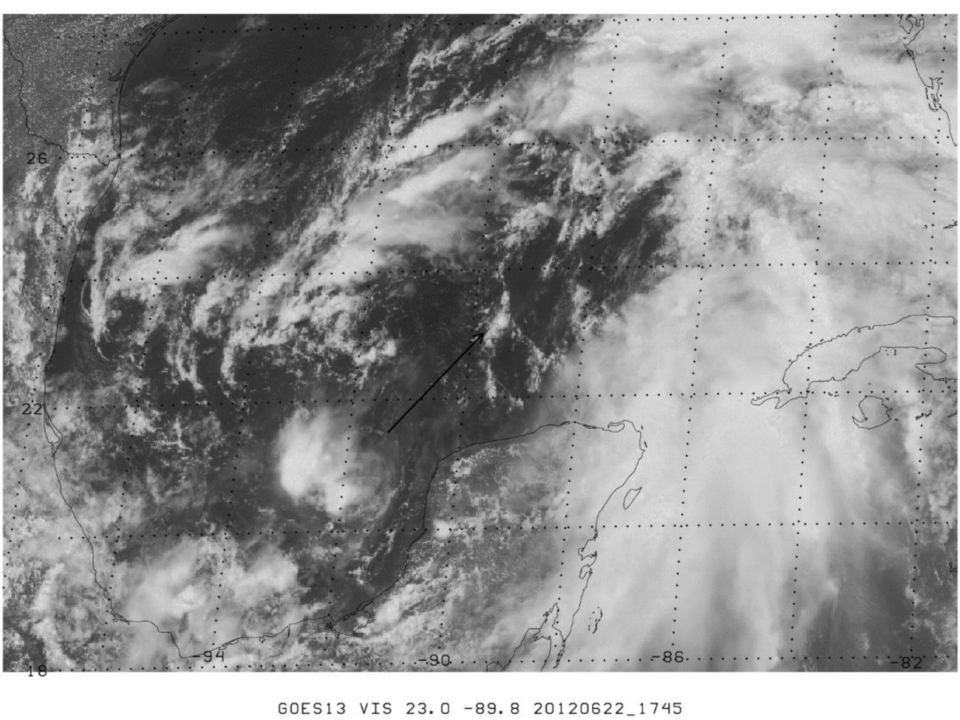
new center

# Step 1A - A T1 classification can be given when...

- A convective cluster has persisted for 12 hr or more
- The cluster has a CSC defined within a 2.5º latitude wide or less area which has persisted for 6 hr
- Associated convection is dark gray (DG) or colder on the Dvorak BD enhancement curve over an area >1.5º diameter less than 2º from the center

# Note on Step 1A

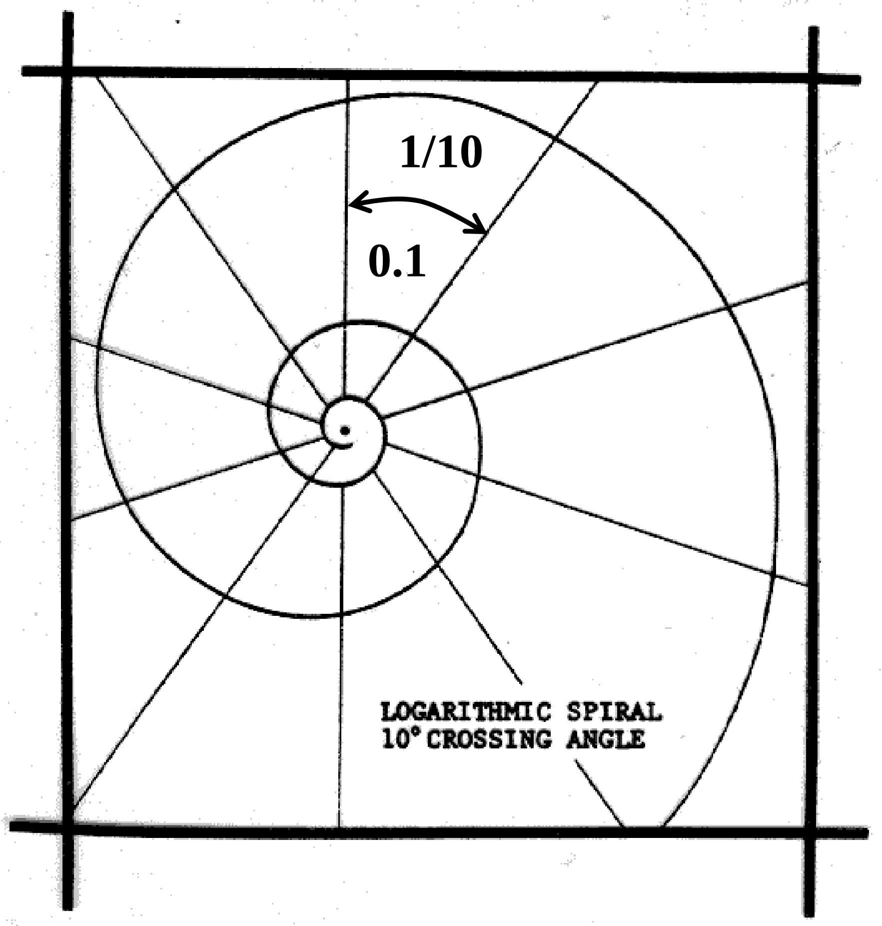
- **An existing CSC that does not meet the criteria of Step 1A can be tracked as a system "too weak to classify" - a location without an intensity estimate**



**Pre-Debby (2012) low – too weak to classify using the Dvorak Technique**

# Step 2 - Analysis of the cyclone cloud pattern

- The cloud pattern analysis produces the Data-T (DT) number intensity estimate
- Tool: Log 10º spiral for measuring curved bands
- Tool: BD enhancement for infrared imagery
- Cloud patterns can change considerably on time scales of a few hours
- Recognizing the correct cloud pattern is vital to a proper intensity analysis

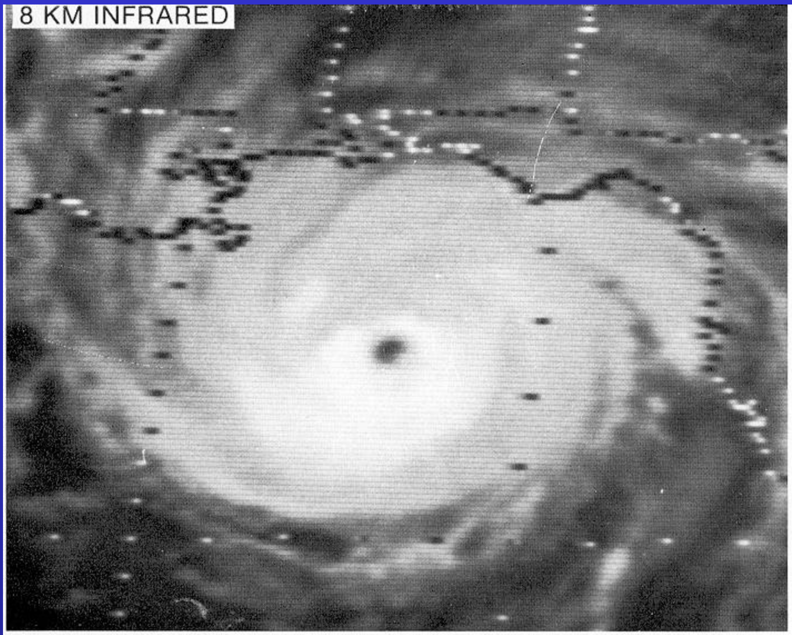


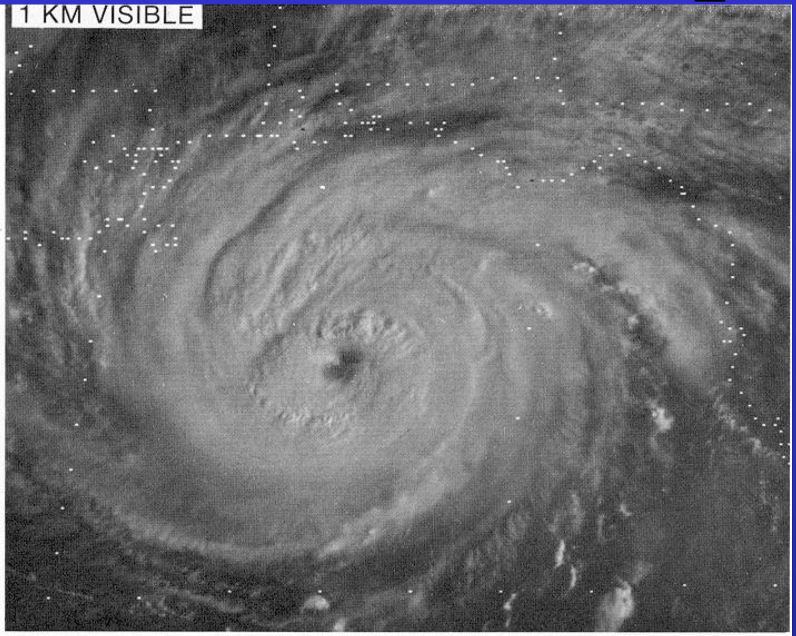
# BD Enhancement Curve

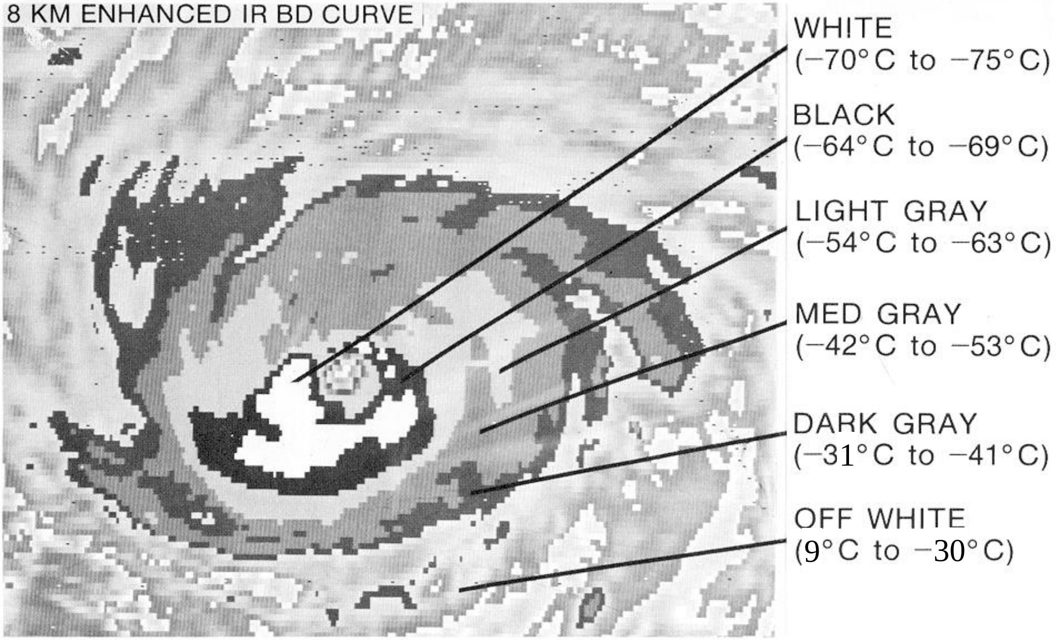
| Segment Number | Color Range | Cloud Top Temperature Range (°C) | Name/Abbreviation |
|---|---|---|---|
| 2 | 0-255 | >9.0 | Warm Medium Gray (WMG) |
| 3 | 109-202 | 9.0 to -30 | Off White (OW) |
| 4 | 60-60 | -31 to -41 | Dark Gray (DG) |
| 5 | 110-110 | -42 to -53 | Medium Gray (MG) |
| 6 | 160-160 | -54 to -63 | Light Gray (LG) |
| 7 | 0-0 | -64 to -69 | Black (B) |
| 8 | 255-255 | -70 to -75 | White (W) |
| 9 | 135-135 | -76 to -80 | Cold Medium Gray (CMG) |
| 10 | 85-85 | <-80 | Cold Dark Gray (CDG) |

**The BD enhancement curve was developed in an era of 256 shades of gray technology.**

# BD Enhancement Curve Example





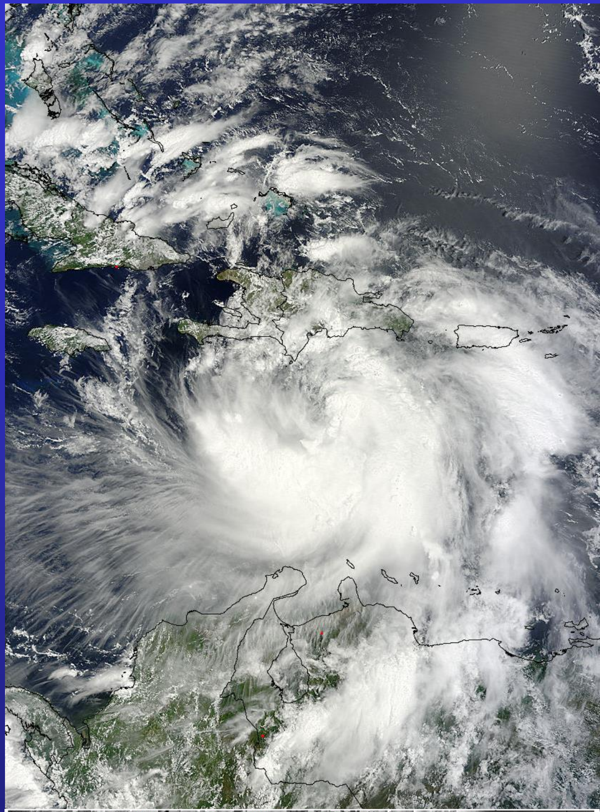


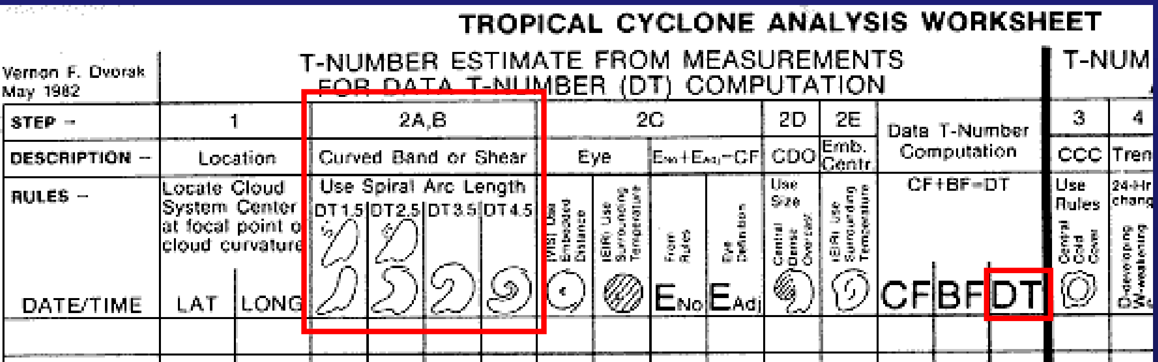
TROPICAL CYCLONE ANALYSIS
**SATELLITE DATA**
**COMPARISON EXERCISE**
**HURRICANE FREDERIC**
1331 GMT 12 September 1979

**On this image, light gray (LG) is the coldest BD color shade that completely surrounds the eye.**

# Step 2A – Measuring Curved Bands

- Fit the spiral parallel to the inner edge of the band (VIS) or to the coldest tops in the band (IR)
- Measure only the primary band of the cyclone - other bands don't count
- Endpoints of bands can be rather subjective
- Important: The center of the log 10° spiral is usually not the center of the cyclone!
- Note: Nature does not always produce bands with 10 degrees crossing angles ☺





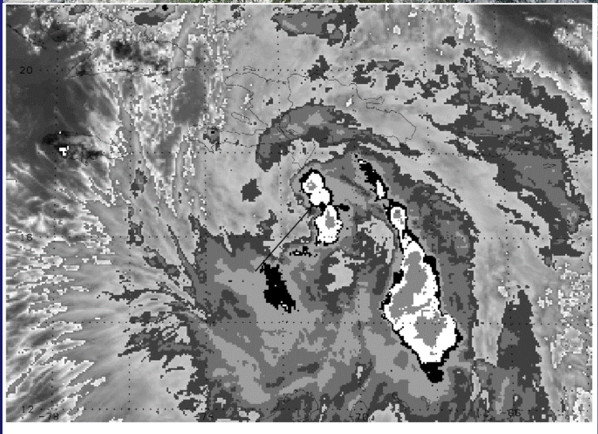
TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

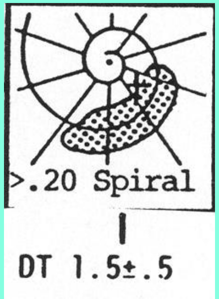
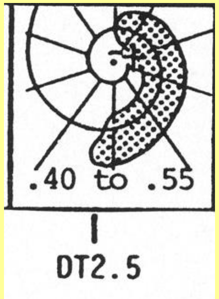
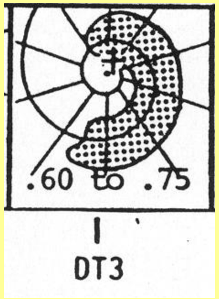
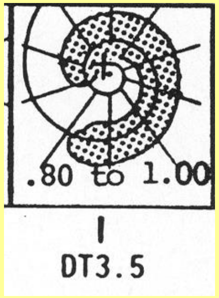
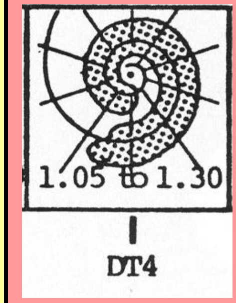
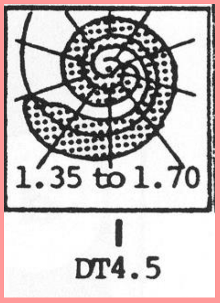
T-NUM

| STEP → | 1 | 2A,B | 2C | | 2D | 2E | Data T-Number Computation | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|
| DESCRIPTION – | Location | Curved Band or Shear | Eye | $E_{No}+E_{Adj}-CF$ | CDO | Emb. Centr | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point o cloud curvature | Use Spiral Arc Length<br>DT1.5 DT2.5 DT3.5 DT4.5 | (VIS) Use Embedded Distance<br>(EIR) Use Surrounding Temperature | From Rules<br>Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| DATE/TIME | LAT LONG | | | E<sub>No</sub> E<sub>Adj</sub> | | | CF BF DT | | |



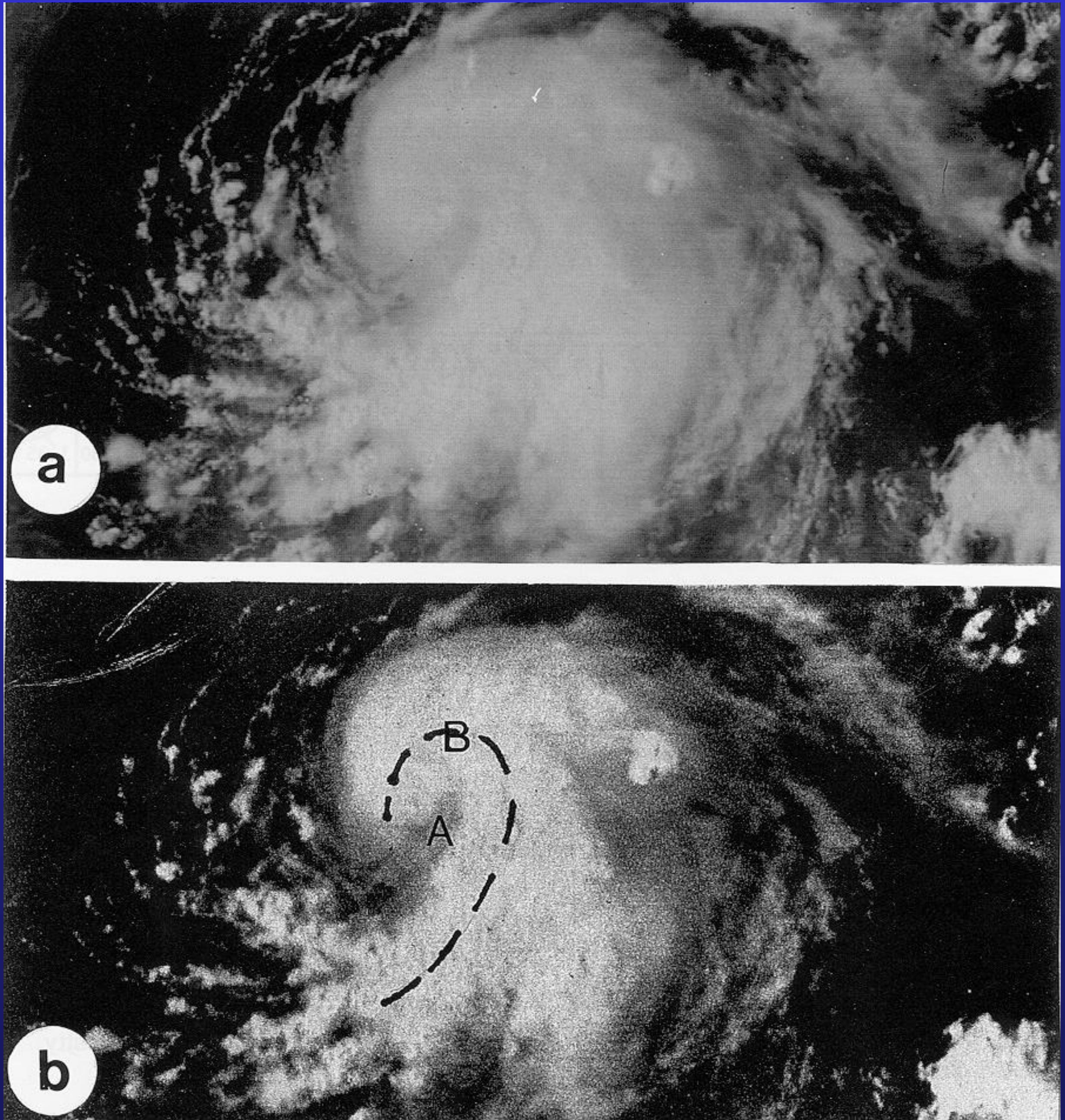
GOES13 IR 16.7 -71.2 20120824_1745

# Step 2A - Curved Band Patterns

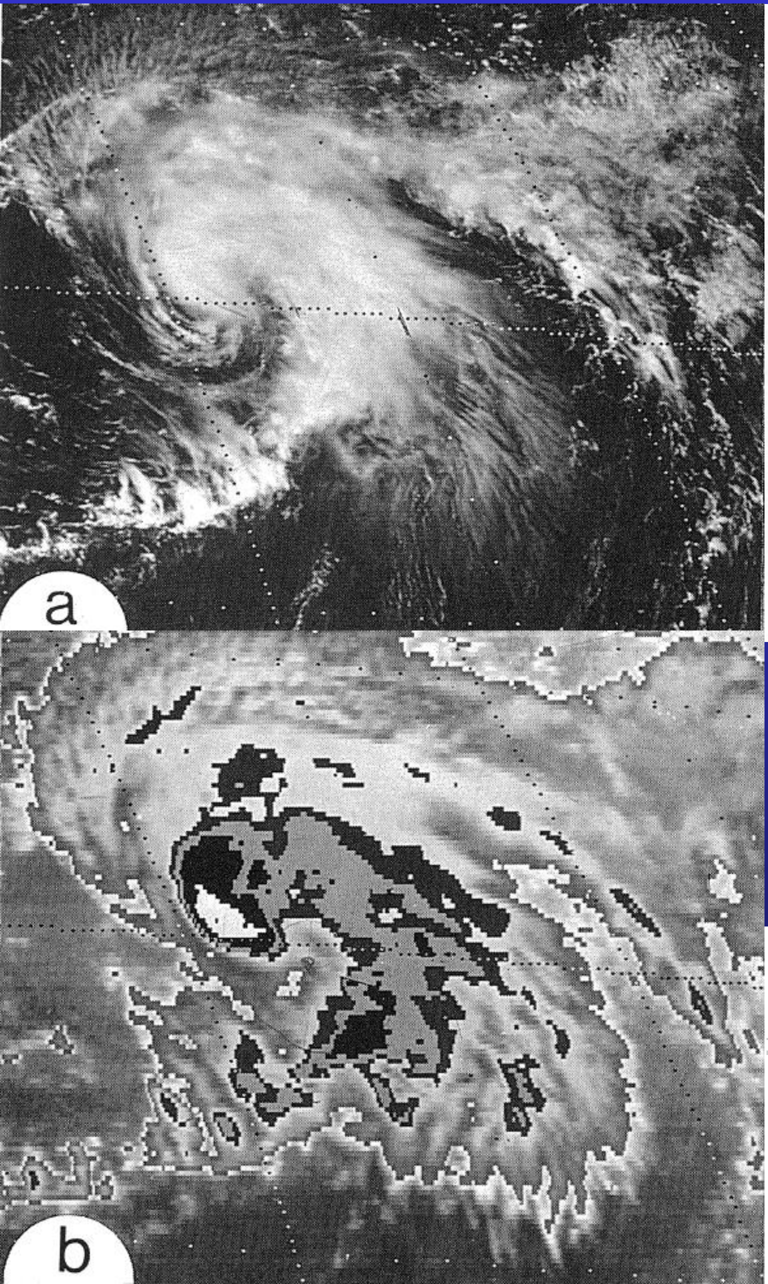
| Flow chart images |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Spiral arc distance (tenths along log 10° spiral) | 0.20 - 0.35 | 0.40 - 0.55 | 0.60 - 0.75 | 0.80 - 1.00 | 1.05 - 1.30 | 1.35 - 1.70 |
| Data-T Number (DT) | 1.0 to 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 |

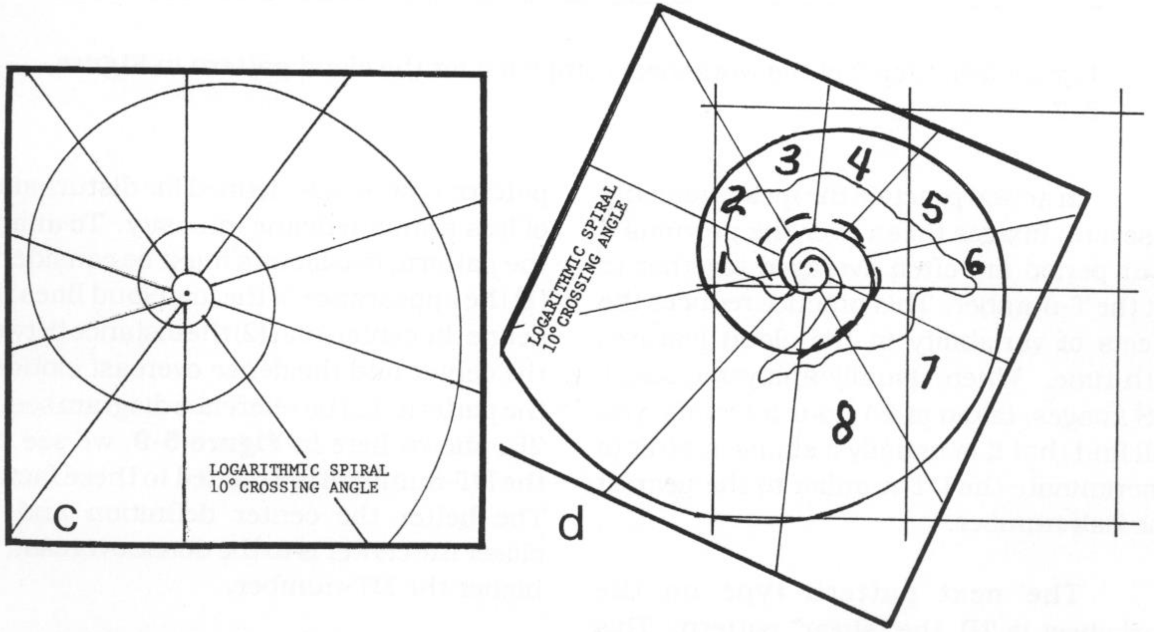
These patterns are for both visible and infrared imagery.
Use banding eyes in Step 2C for unusual band widths and lengths in visible imagery.

# Step 2A - Curved Band Example

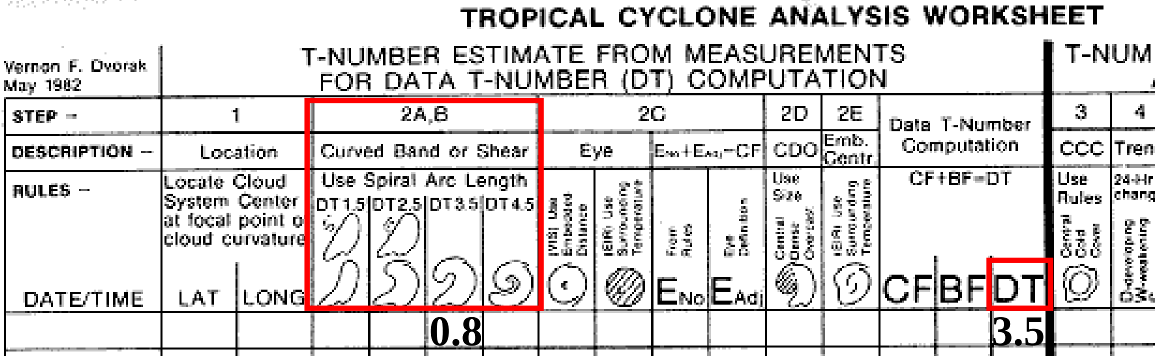


# Step 2A - Measuring Curved Bands





**0.8 Banding - DT=3.5**



TROPICAL CYCLONE ANALYSIS WORKSHEET

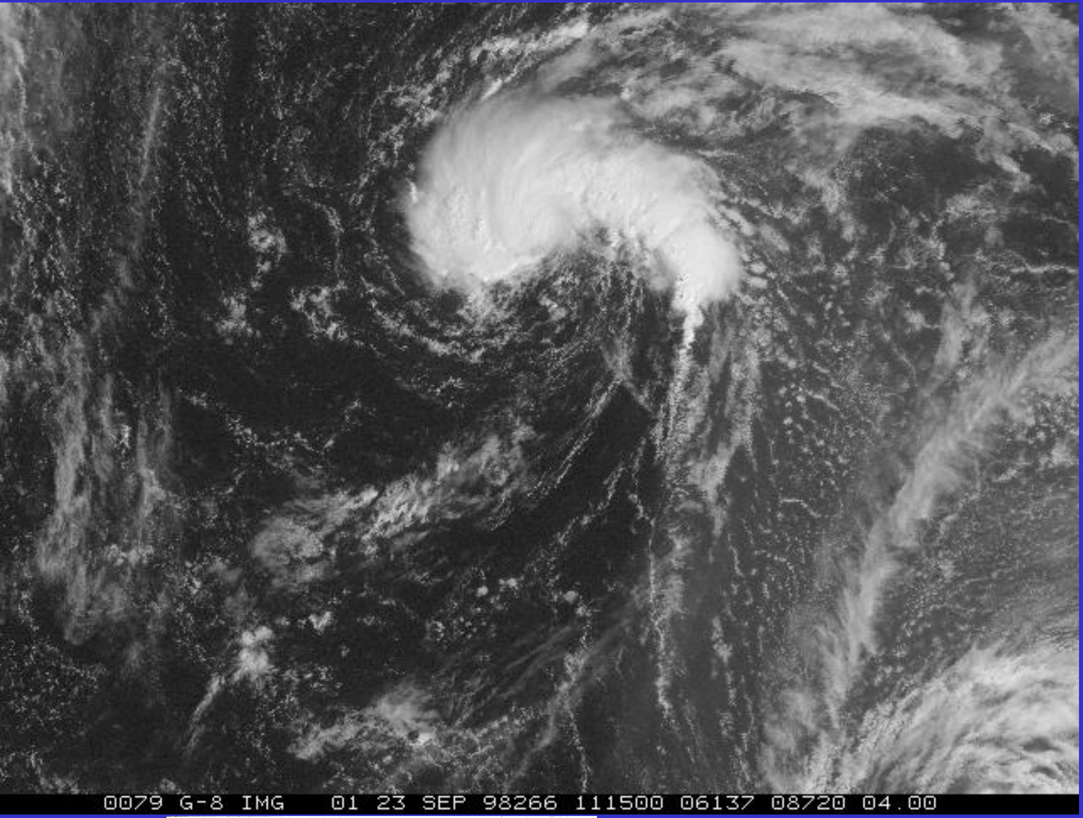
Vernon F. Dvorak
May 1982

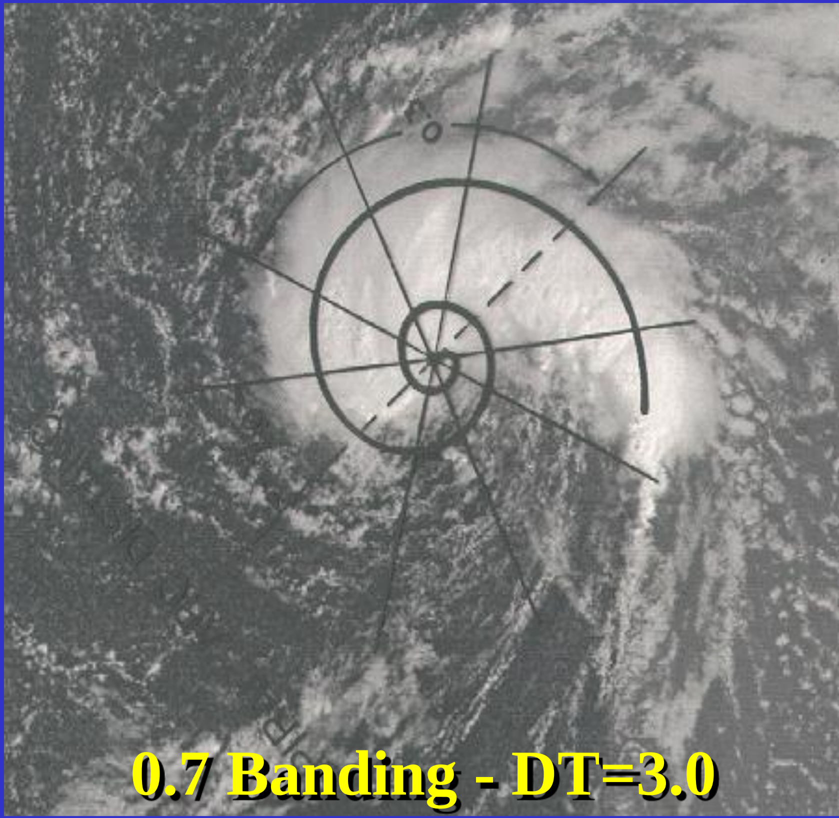
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

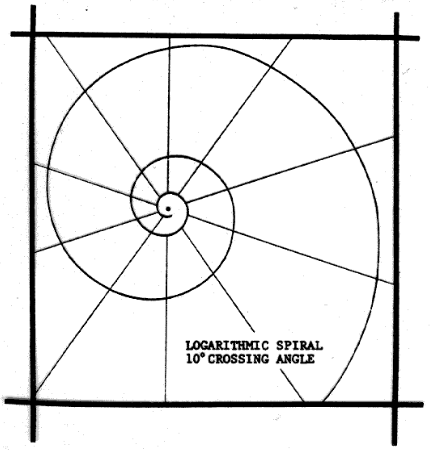
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point o cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr chang |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Central Dense Overcast | (EIR) Use Surrounding Temperature | | | | Central Cold Cover | Developing Weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | 0.8 | | | | | | | | | | 3.5 | | |

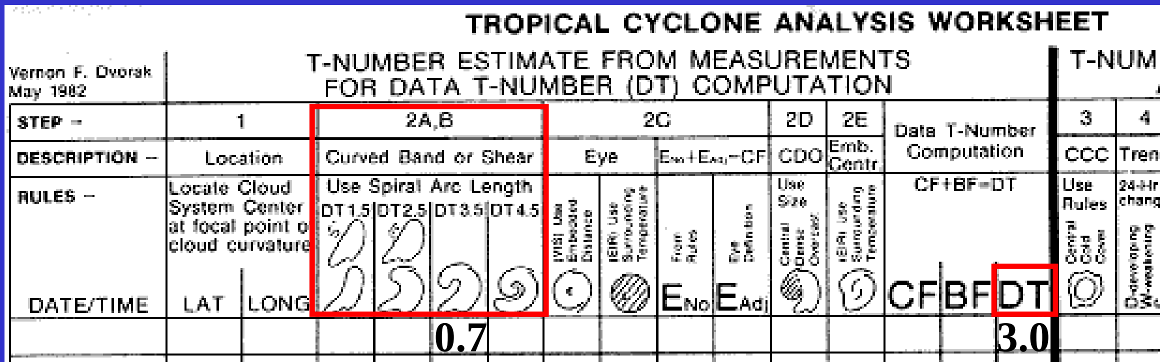
# Step 2A - Measuring Curved Bands





0.7 Banding - DT=3.0





TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

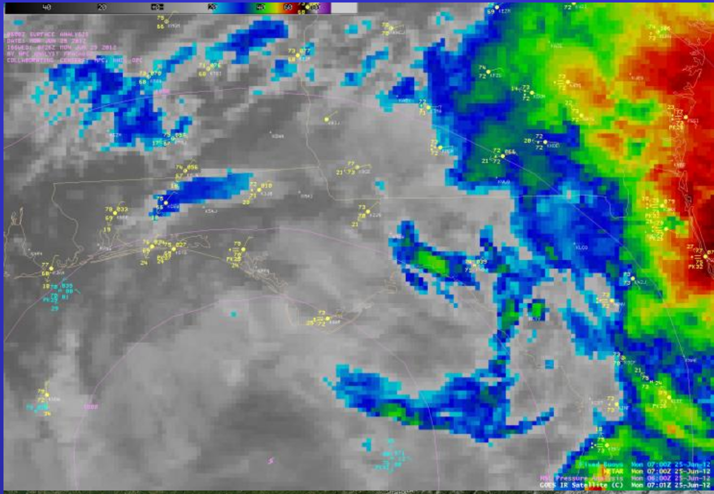
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

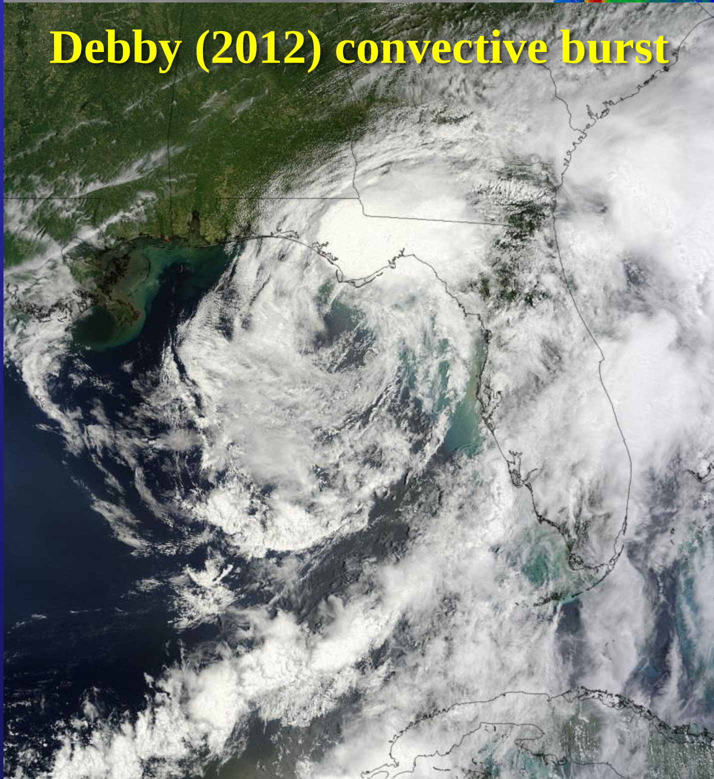
T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point o cloud curvature | | Use Spiral Arc Length | | | | (WIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | 0.7 | | | | | | | | | | 3.0 | | |

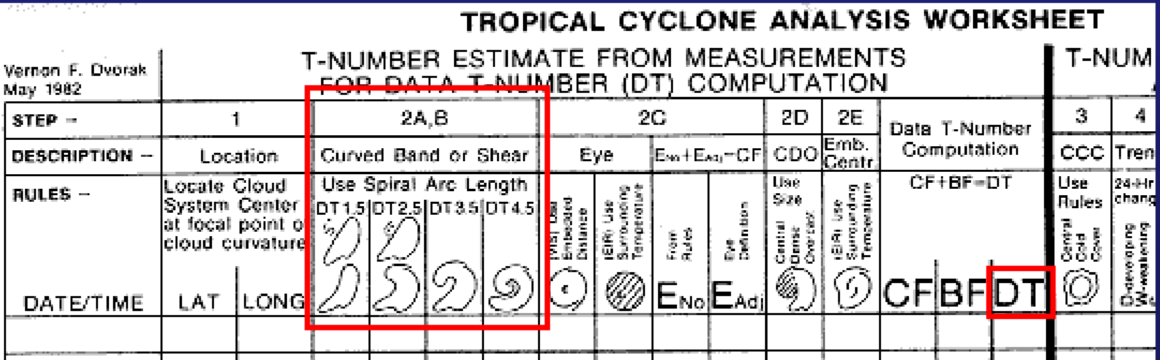
# Step 2B – Measuring Shear Patterns

- **Measure the distance (in degrees of latitude) from the low level center to the edge of the dense overcast (VIS) or to the edge of the DG shade (IR)**
- **The edge of the convection can be rather subjective**
- **Shear patterns tend to be rather unstable, as the convection often shows strong pulses or bursts. Therefore the DT is often considered not to be clear cut**





**Debby (2012) convective burst**



TROPICAL CYCLONE ANALYSIS WORKSHEET

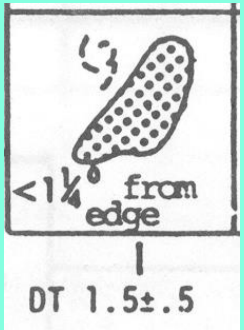
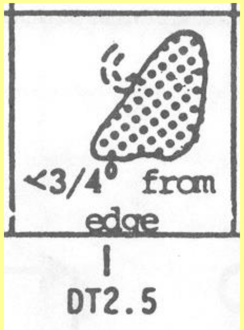
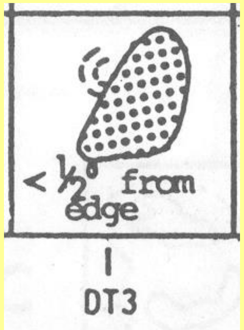
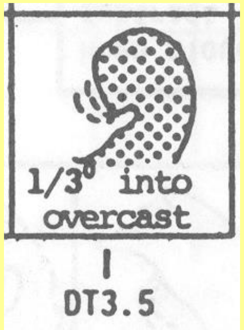
Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

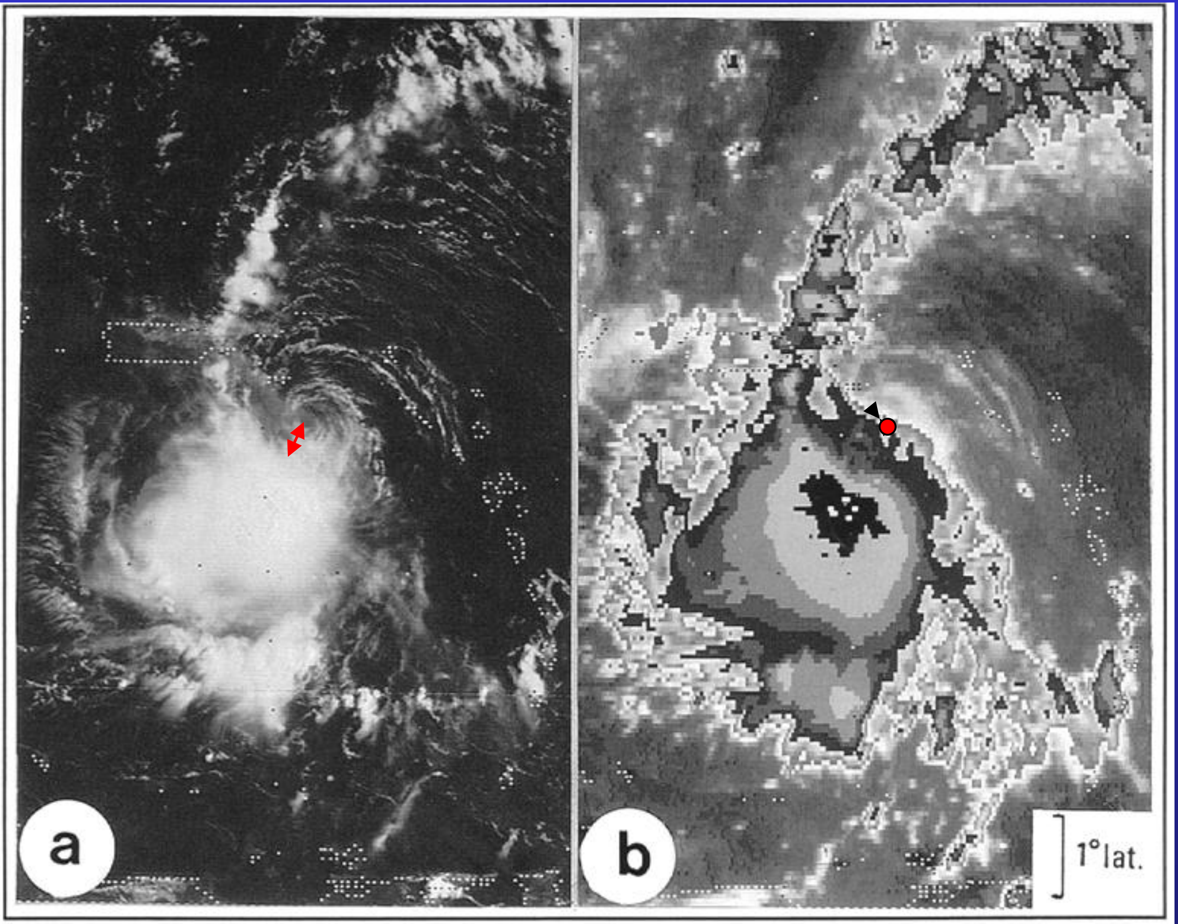
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point o cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |

# Step 2B - Shear Patterns

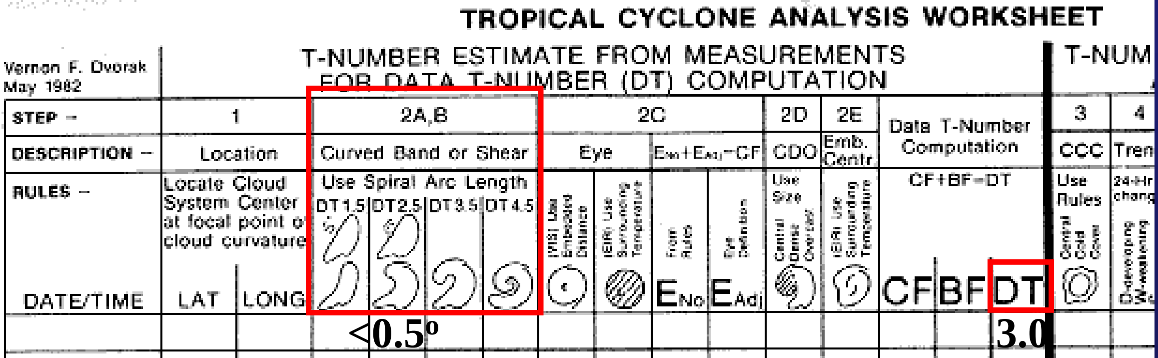
| | | | | |
|---|---|---|---|---|
| Flow chart images |  |  |  |  |
| Distance from edge of convection or DG (tenths of deg latitude) | 1.25 – 0.75 | 0.74 – 0.50 | 0.49 from Cnvtn to 0.32 into Cnvtn | >0.33 into Cnvtn |
| Data-T Number (DT) | 1.0 to 2.0 | 2.5 | 3.0 | 3.5 |

**Note: This is the 1984 version of the shear pattern measurements**

# Step 2B - Measuring Shear Patterns



**Shear Distance < 0.5°**
**DT=3.0**



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

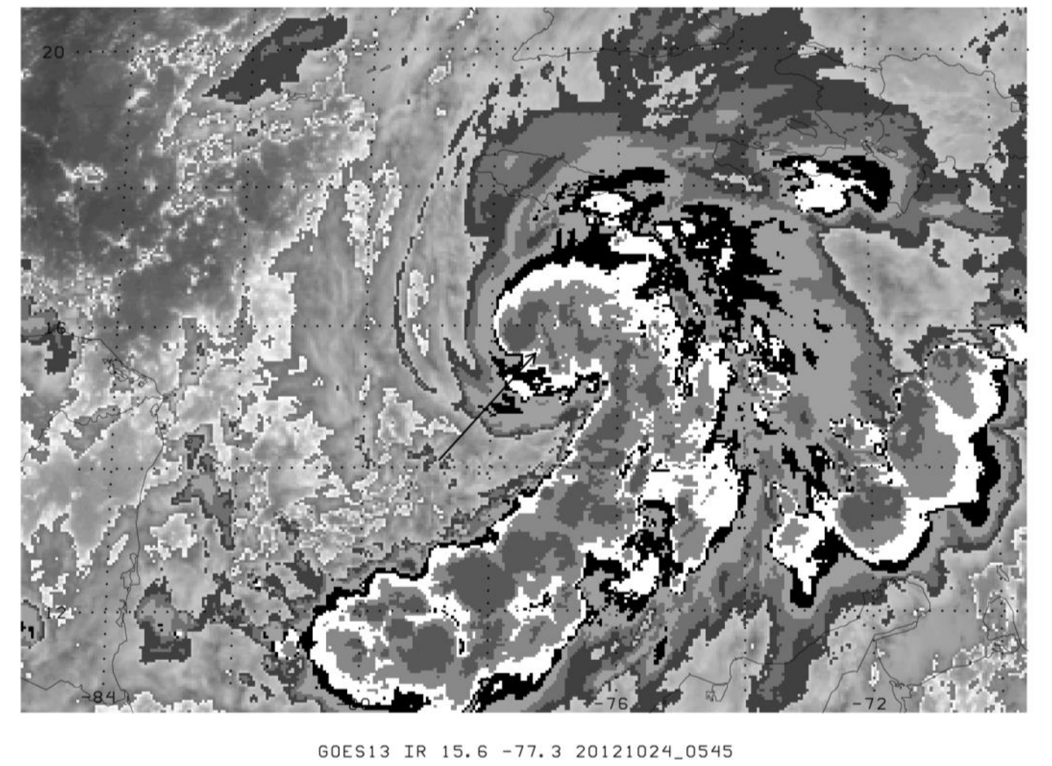
T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point o cloud curvature | | Use Spiral Arc Length<br>DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>D=developing W=weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | <0.5° | | | | | | | | | | | | 3.0 | | |

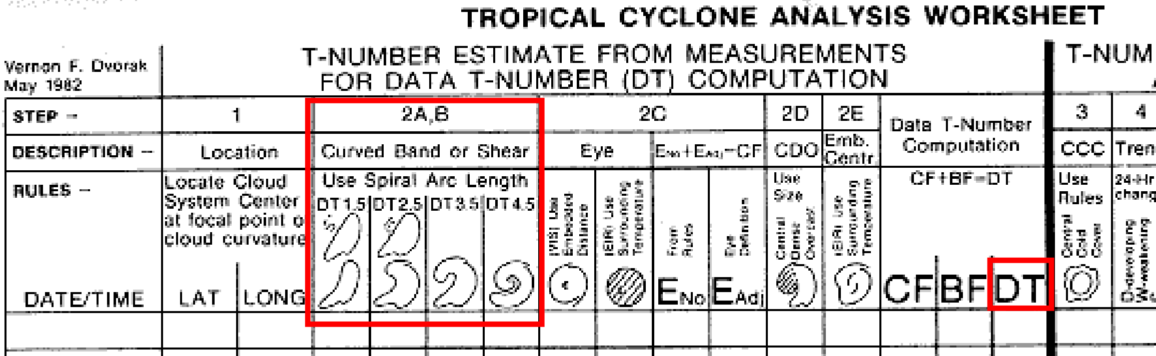
# Notes on Steps 2A and 2B

- When available, VIS curved band and shear patterns are preferable to their IR counterparts
- Curved bands and shear patterns directly produce DT numbers
- The measurements are the same for both VIS and IR imagery
- A possible intensity adjustment in the IR curved band pattern: Add 0.5 to the DT if the curved band is White (W) or colder



GOES13 IR 15.6 -77.3 20121024_0545

Sandy (2012) with a White (W) or colder band – add 0.5 to the band DT!



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

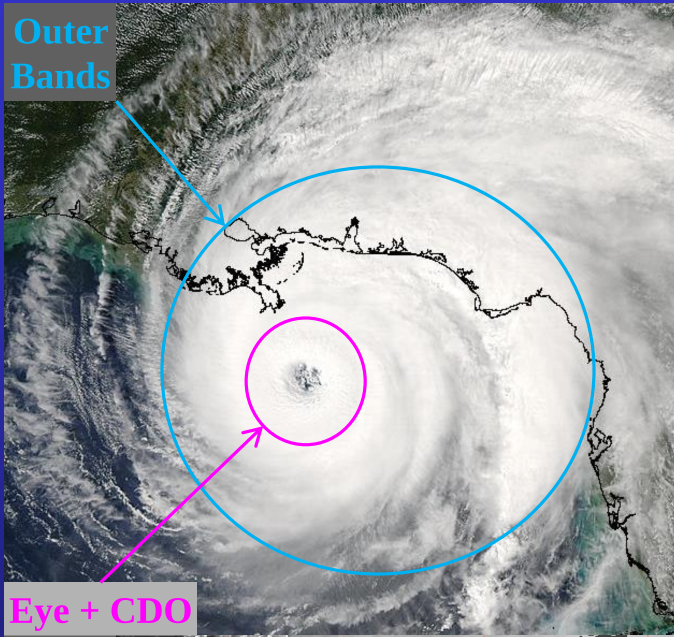
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

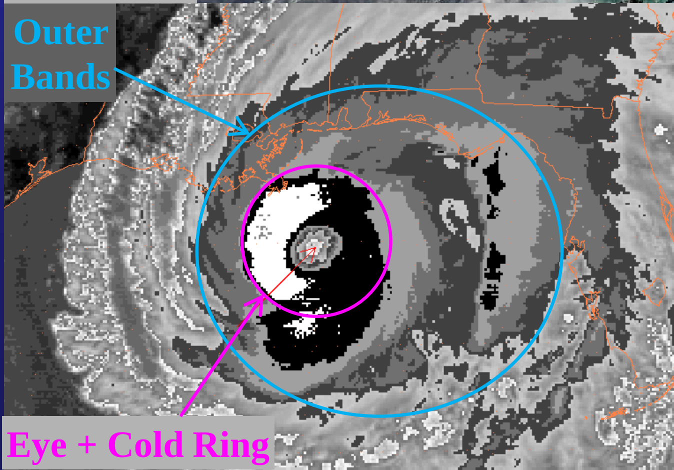
T-NUM

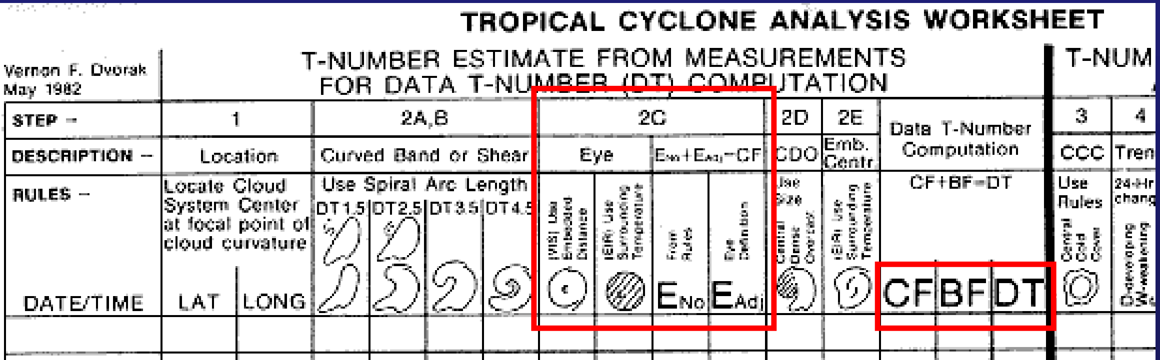
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point o cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr chang |
| DATE/TIME | LAT | LONG | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules<br>$E_{No}$ | Eye Definition<br>$E_{Adj}$ | Central Dense Overcast | (EIR) Use Surrounding Temperature | CF | BF | DT | Central Cold Cover | Developing Weakening |
| | | | | | | | | | | | | | | | | | |

# Step 2C – Measuring Eye Patterns
# Some Assembly Required!

- Find the eye number (E-number)
- Perform an Eye Adjustment
- Create the Central Feature (CF) number from the E-number and Eye Adjustment
- Add applicable banding features (BF) to the CF number to get the DT number
- There are significant differences between what is measured in the VIS and IR eye patterns as shown on the flow chart







TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

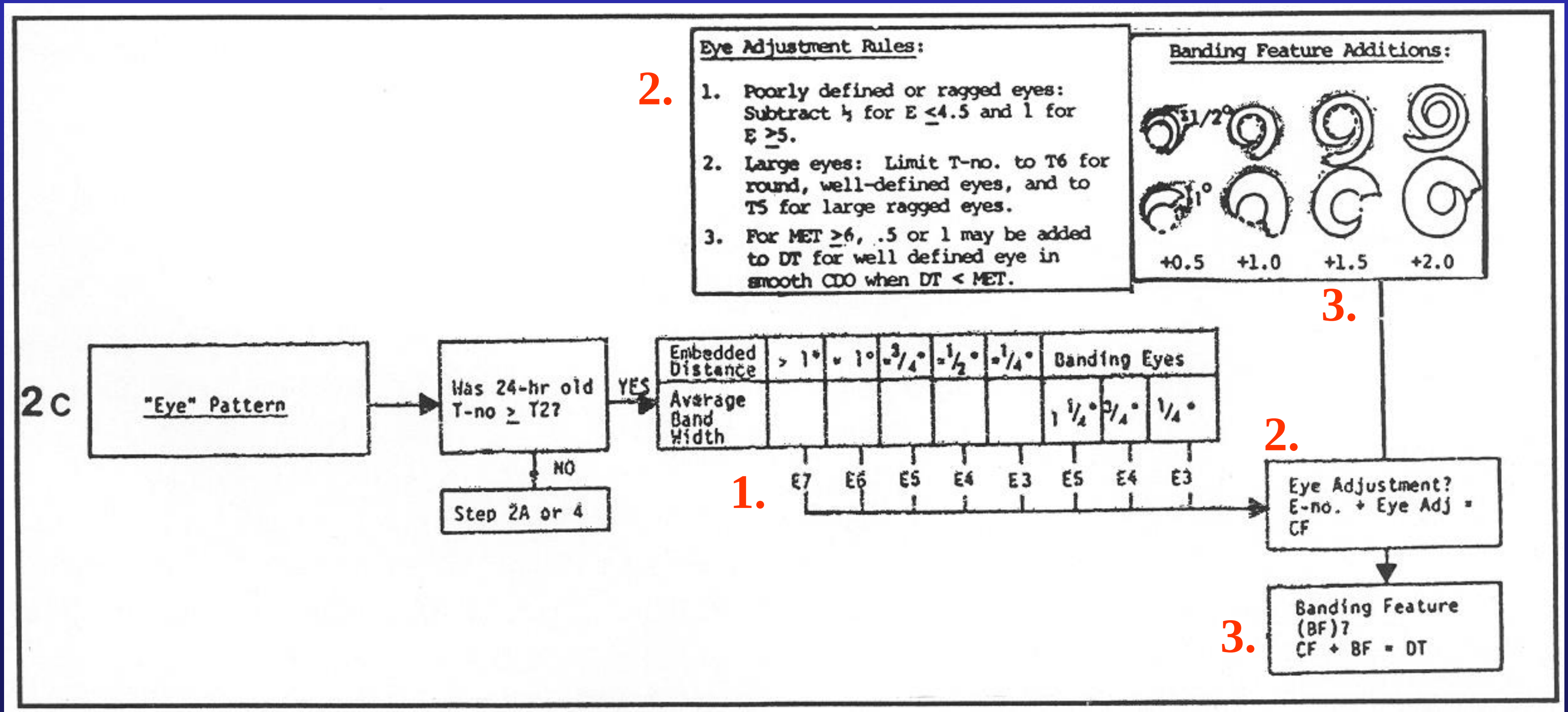
T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}=CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length<br>DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |

# Step 2C - Visible Eye Patterns

1. Measure the distance ('embedded distance') from the center of the eye to the edge of the Central Dense Overcast (E-number)
2. Make eye adjustment based on size and clarity of eye (E-Number + Eye Adjustment = CF Number)
3. Add BF for applicable outer banding (CF + BF = DT)



**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.

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

Banding Feature (BF)?
CF + BF = DT

# Step 2C - Eye Patterns

## Visible Technique

Is the 24 hour old FT > 2.0? If not, go to step 2A or step 4.

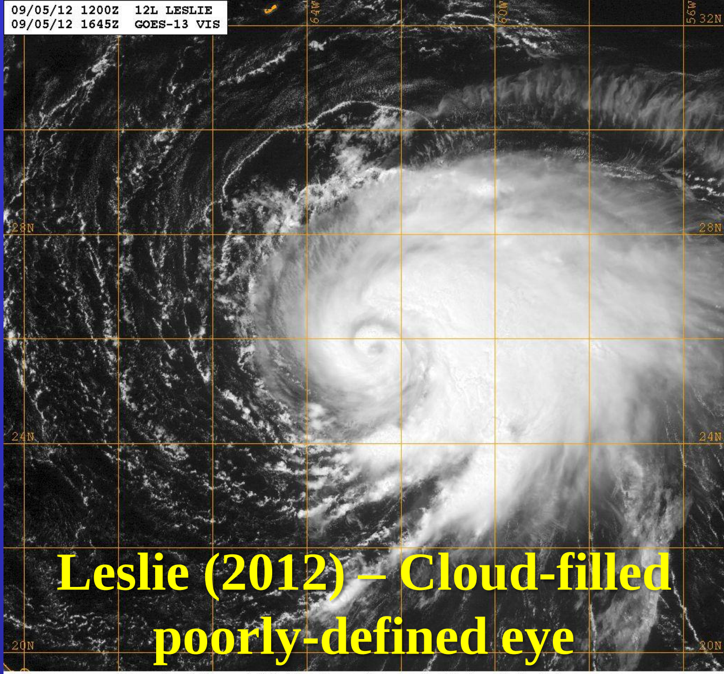
| Eye in CDO - Embedded Distance (deg) | >1 | ~1 | ~0.75 | ~0.5 | ~0.25 |
|---|---|---|---|---|---|
| Banding Eye - Avg. Width of Band Around Eye (deg) | | | 1.25 | 0.75 | 0.25 |
| Eye Number (E#) | 7.0 | 6.0 | 5.0 | 4.0 | 3.0 |

Note: You can interpolate between the eye numbers when appropriate!

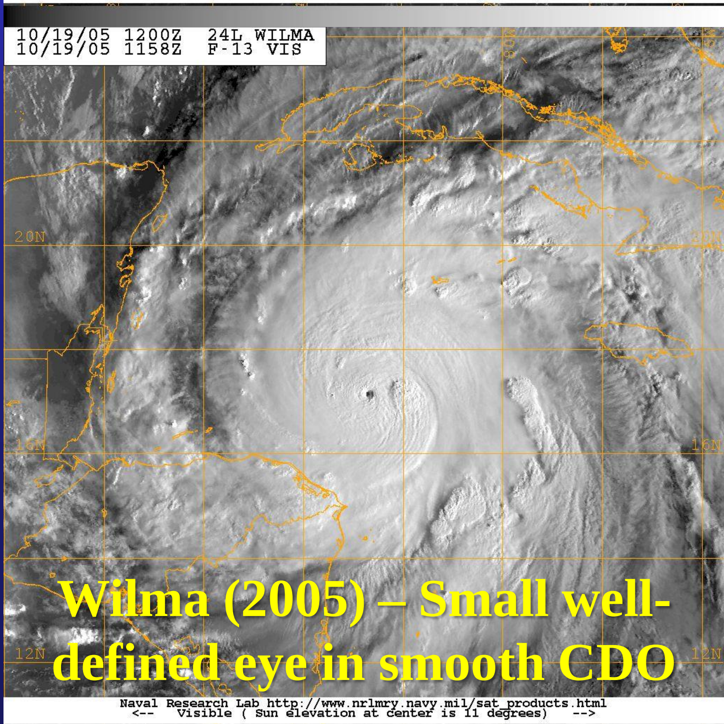
# Step 2C - Visible Eye Adjustment

## Eye Adjustment Rules

1. Poorly defined or ragged eyes: subtract 0.5 for E≤4.5 and 1 for E≥5
2. Large eyes (30 nm/56 km or greater): Limit T-no to T6 for round well-defined eyes and to T5 for large ragged eyes
3. For MET≥6, 0.5 or 1 may be added to DT for well-defined eye in smooth CDO when DT<MET

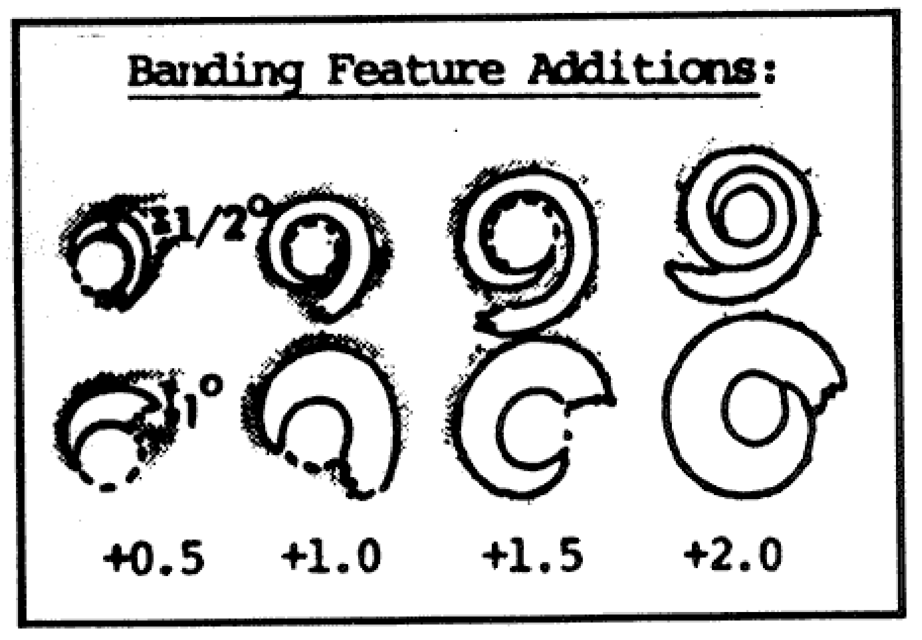


Leslie (2012) – Cloud-filled poorly-defined eye



Wilma (2005) – Small well-defined eye in smooth CDO

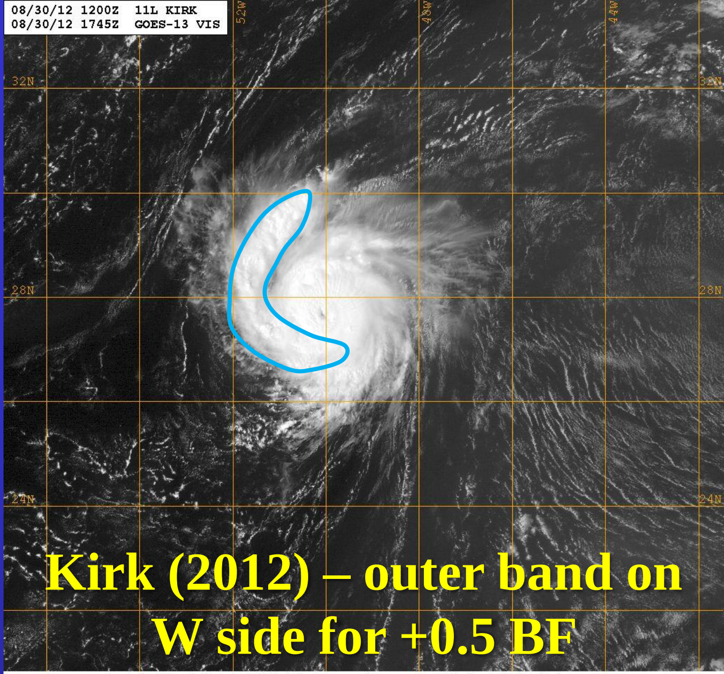
# Step 2C - Visible Outer Banding



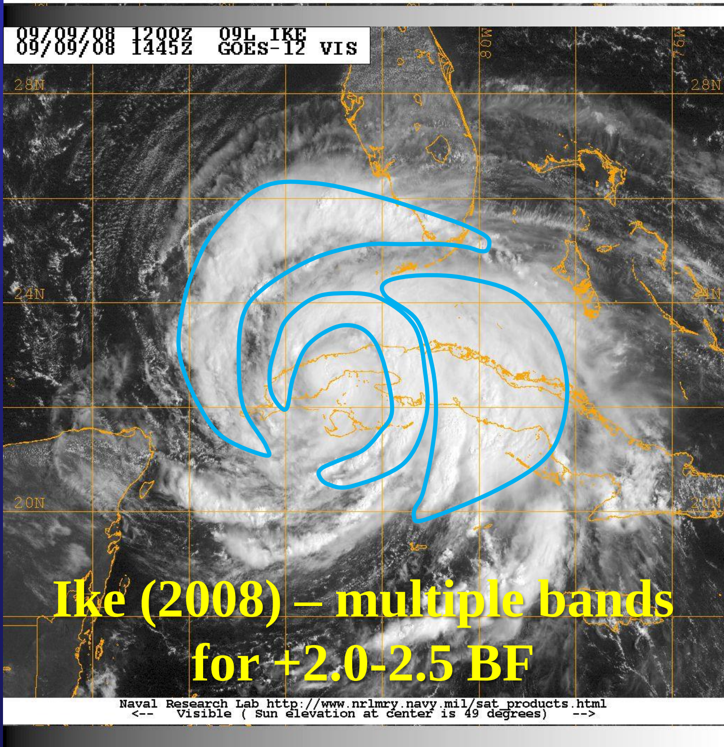
**Banding Feature (BF) Numbers:**

**Match the banding outside of the central convection to that shown in the pictograph.**

**Note: You can add multiple bands when applicable up to a total of 2.5 BF numbers.**



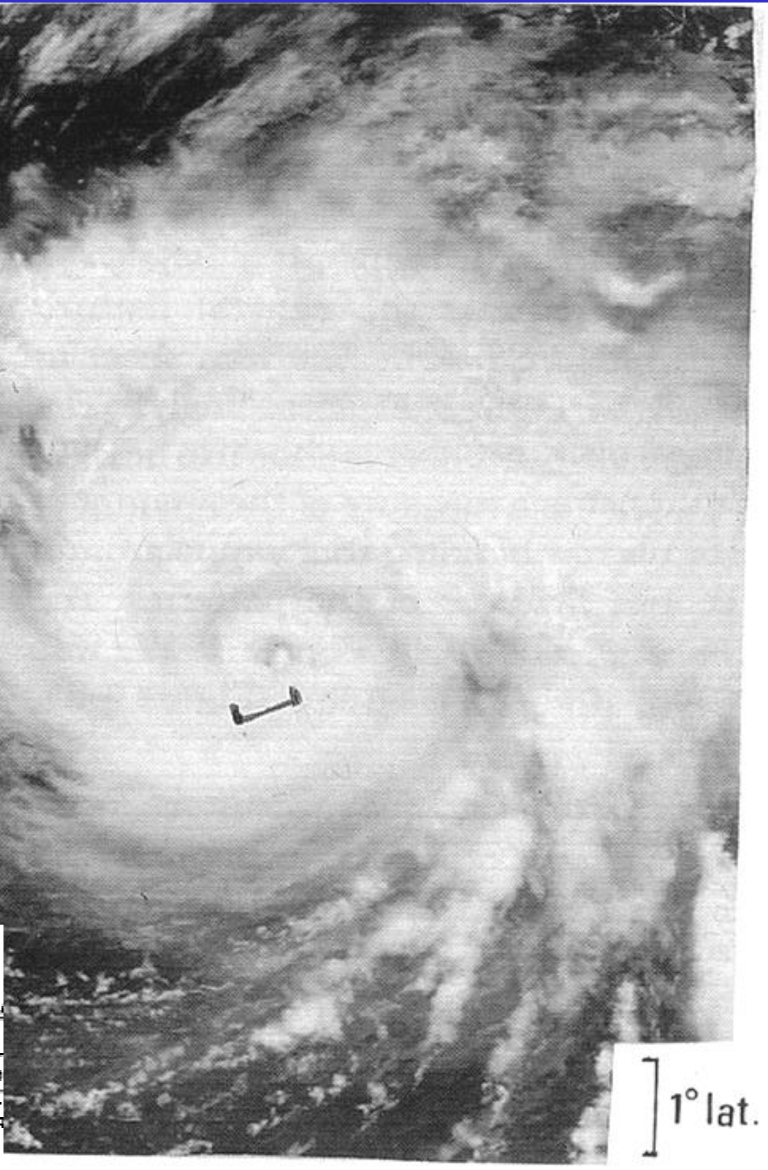
Kirk (2012) – outer band on W side for +0.5 BF

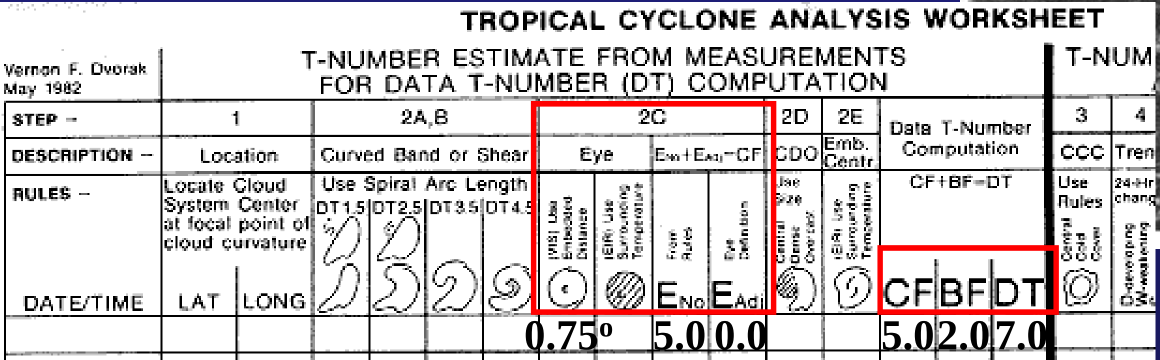


Ike (2008) – multiple bands for +2.0-2.5 BF

# Step 2C - Measuring a Visible Eye

**The eye is ¾ degrees into the CDO (Eye number 5.0), with no Eye adjustment (0.0). This produces a CF5 + 2.0 for banding features ➔ DT=7.0**





TROPICAL CYCLONE ANALYSIS WORKSHEET

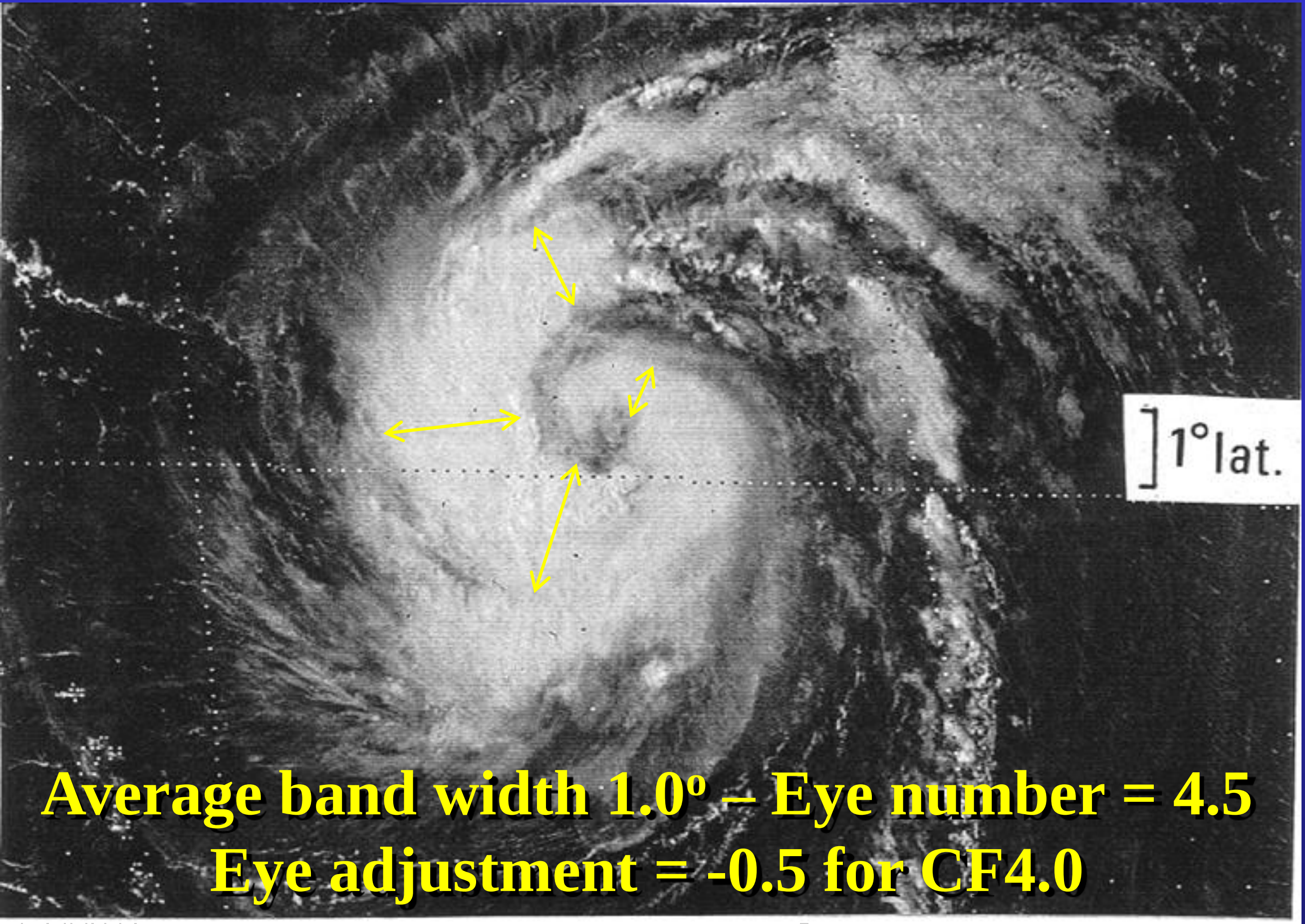
Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

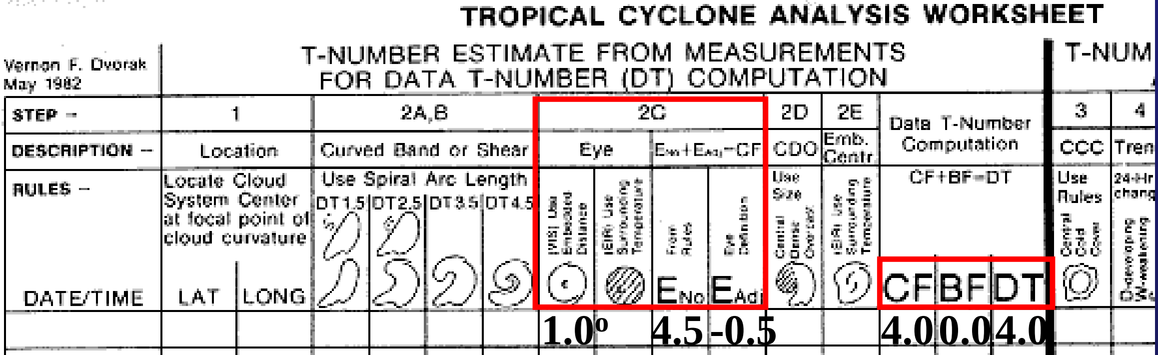
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}=CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules Central Cold Cover | 24-Hr chang D-developing W-weakening |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | | | 0.75° | | 5.0 | 0.0 | | | 5.0 | 2.0 | 7.0 | | |

# Step 2C - VIS Banding Eyes



Average band width 1.0$^o$ – Eye number = 4.5
Eye adjustment = -0.5 for CF4.0

- E-number determined by the <u>average</u> width of the band surrounding the eye
- Also uses eye adjustment rules
- Only used with <u>visible</u> imagery



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

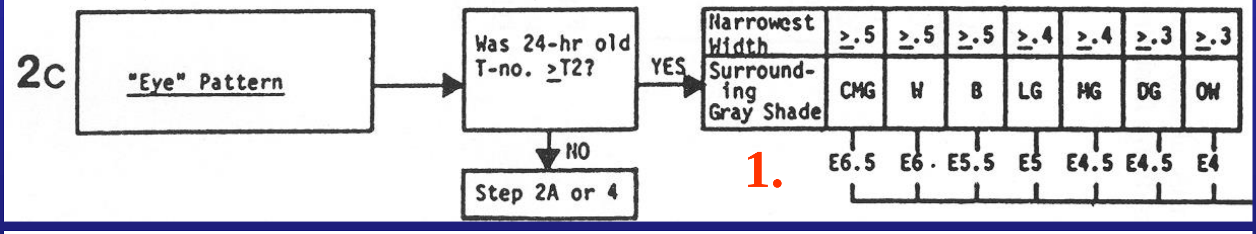
T-NUM

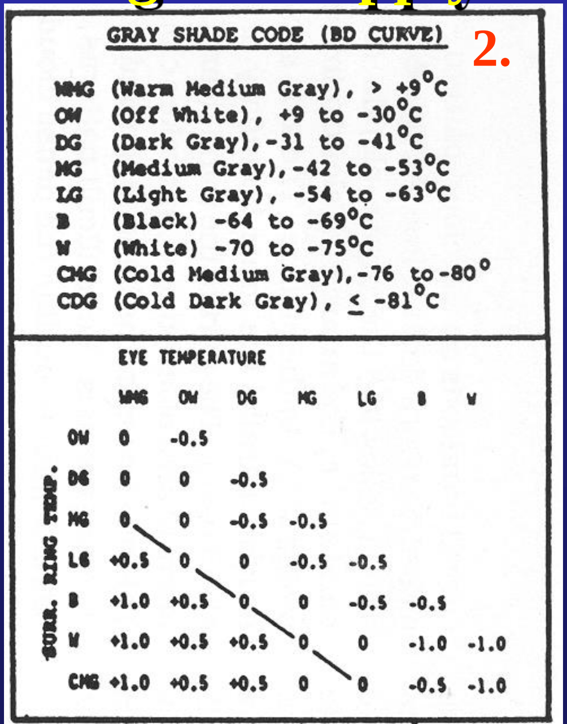
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}=CF$ | | CDO | Emb. Centr | Data T-Number Computation | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr chang |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Central Dense Overcast | (EIR) Use Surrounding Temperature | | | | Central Cold Cover | Developing Weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | | | 1.0$^o$ | | 4.5 | -0.5 | | | 4.0 | 0.0 | 4.0 | | |

Can also used a curved band with 1.2-1.3 banding for a DT=4.0+

# Step 2C - Infrared Eye Patterns

1. **Find the coldest color on the BD enhancement that completely surrounds the eye with a thickness greater than the specified width (closed ring surrounding the eye)**
2. **Make eye adjustment based on the color on the warmest BD enhancement color in the eye (E-Number + Eye Adjustment = CF Number)**
3. **Add BF for applicable banding when IR banding rules apply (CF + BF = DT)**



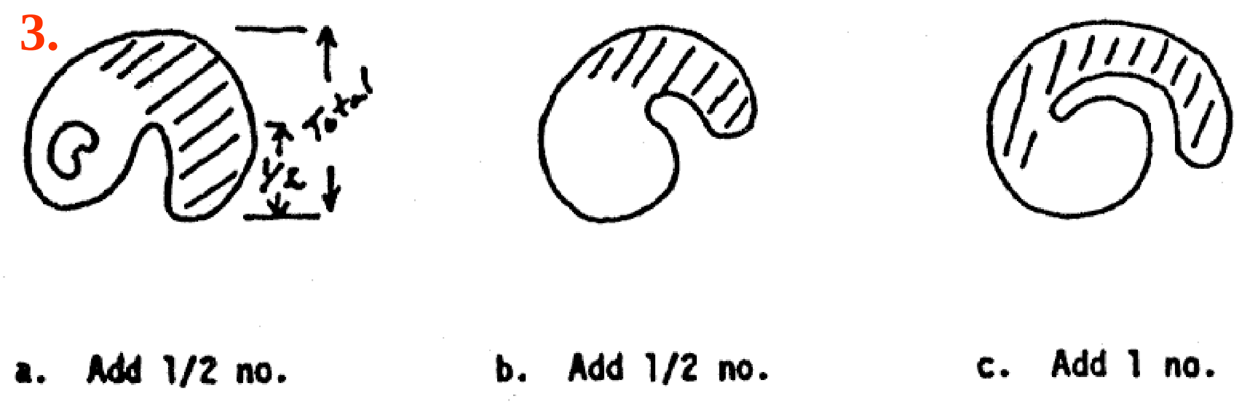

2.

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 |



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

# Step 2C - Eye Patterns

## Infrared Technique

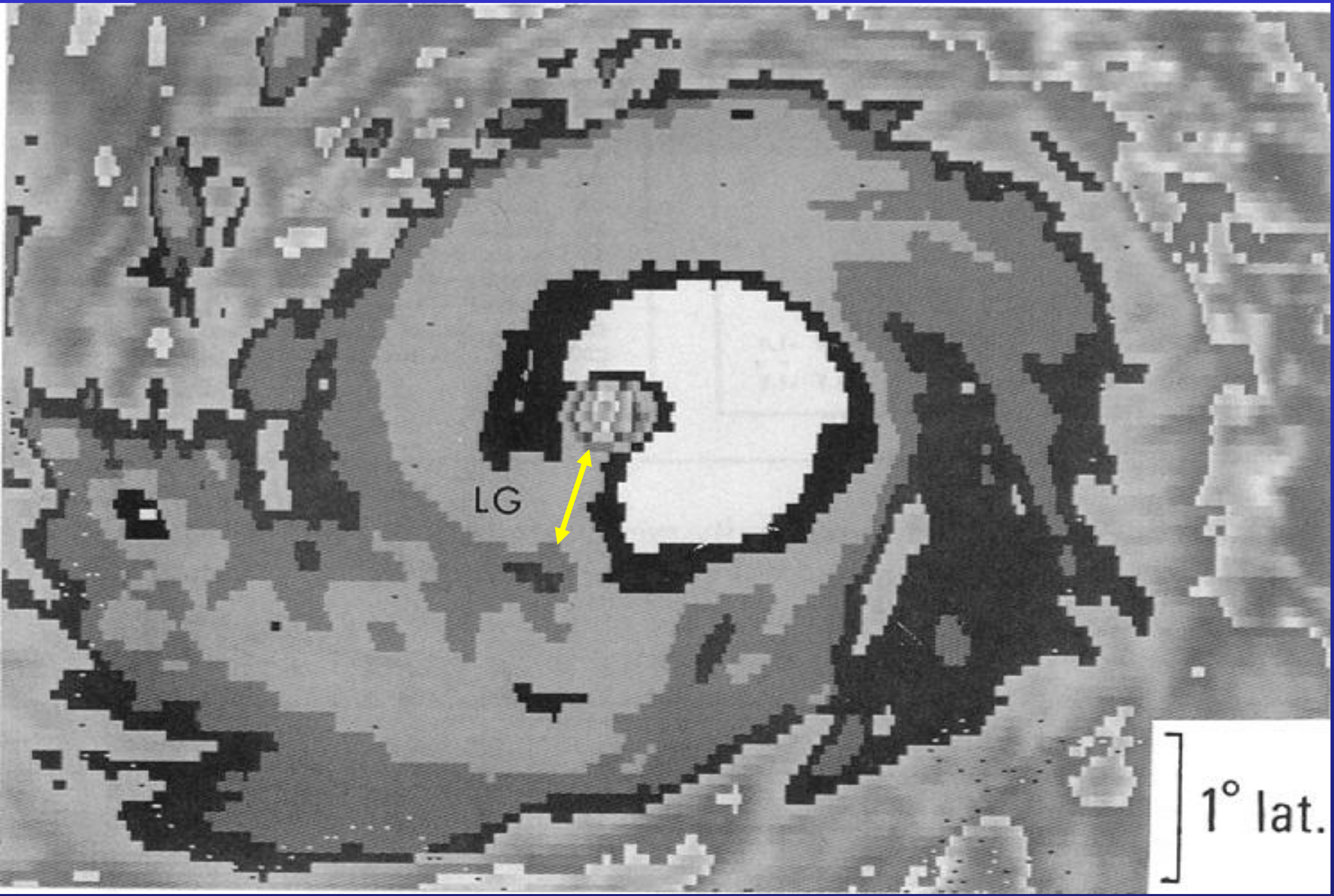
Is the 24 hour old FT > 2.0? If not, go to step 2A or step 4.

| Surrounding BD Color | CMG | W | B | LG | MG | DG | OW |
|---|---|---|---|---|---|---|---|
| Narrowest width (deg) | ≥0.5 | ≥0.5 | ≥0.5 | ≥0.4 | ≥0.4 | ≥0.3 | ≥0.3 |
| Eye Number (E#) | 6.5 | 6.0 | 5.5 | 5.0 | 4.5 | 4.5 | 4.0 |

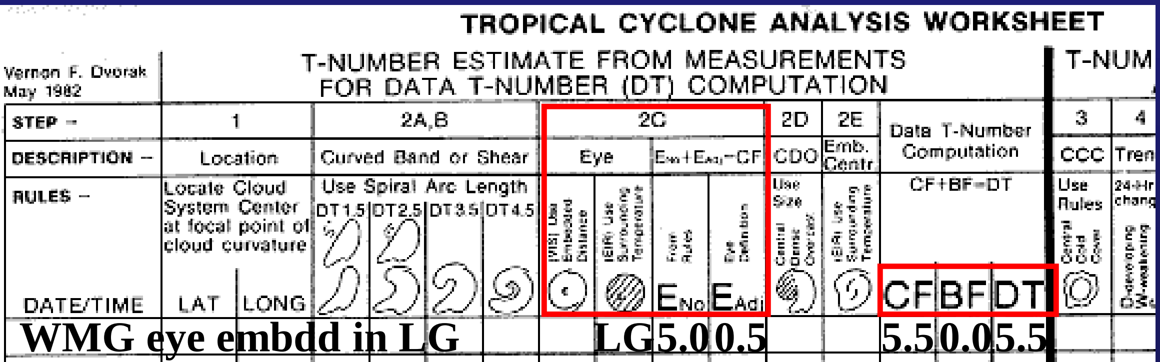
**Eye Adjustment:**

| | Eye Temperature | | | | | | |
|---|---|---|---|---|---|---|---|
| **Surr. BD Color** | **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 |

# Step 2C - Measuring an Infrared Eye



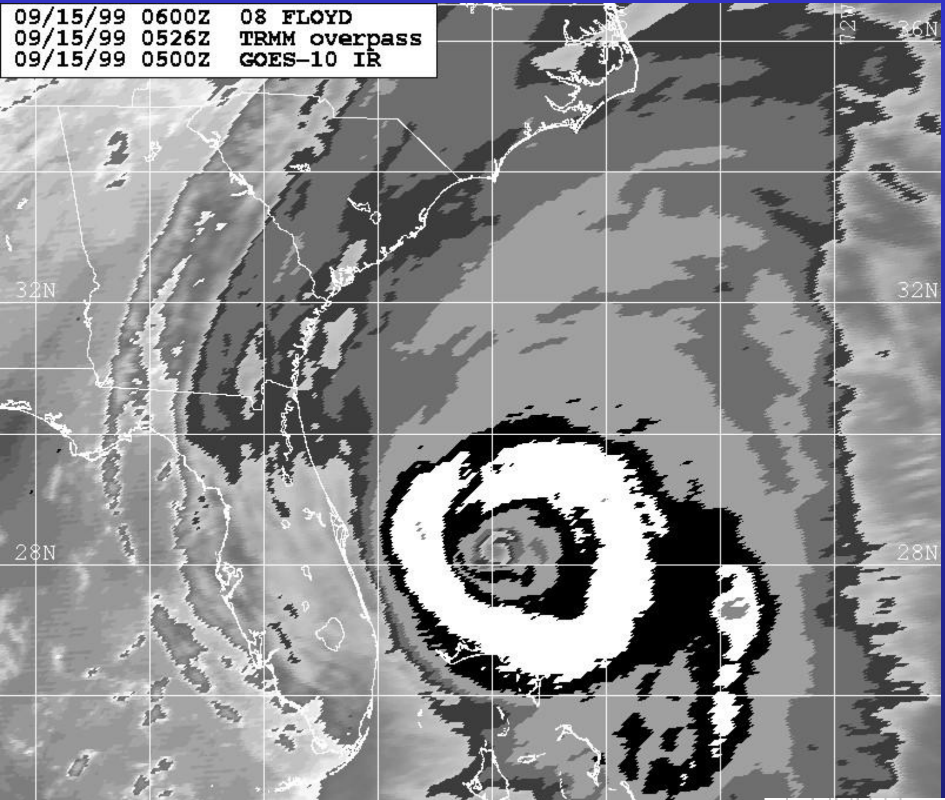
**Light Gray (LG) is the coldest color <u>surrounding</u> the eye that meets the width criteria. The eye temperature is Warm Mediun Gray (WMG). The Eye number is 5.0, while the Eye adjustment is +0.5 - CF=5.5**



TROPICAL CYCLONE ANALYSIS WORKSHEET

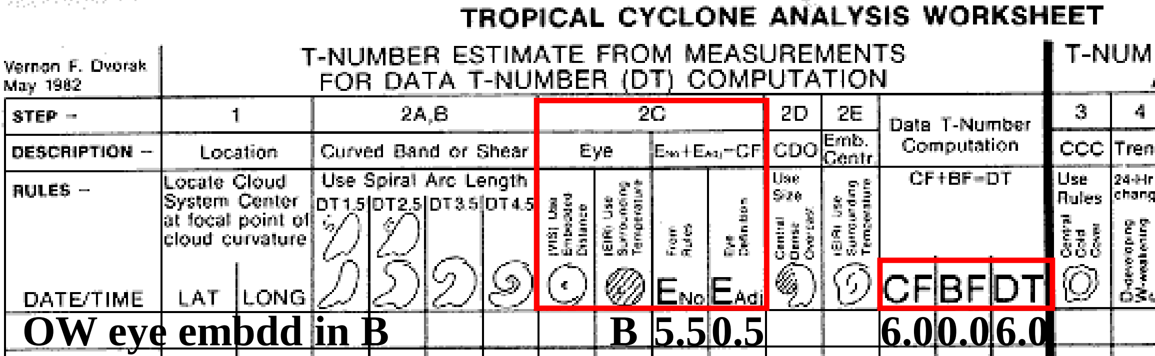
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vernon F. Dvorak<br>May 1982 | T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION | | | | | | | | | | | | | | | T-NUM | |
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}=CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>D-developing W-weakening |
| DATE/TIME | LAT | LONG | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| WMG eye embdd in LG | | | | | | | | LG | 5.0 | 0.5 | | | 5.5 | 0.0 | 5.5 | | |

# Step 2C - Size Doesn't Matter for an Infrared Eye



**The coldest color completely surrounding the eye is Black (B) even though that color is more than 60 n mi from the eye in some areas. The eye temperature is Off White (OW). The Eye number is 5.5 and the Eye adjustment is 0.5 – CF=6.0**

**Note: This is not in total agreement with page 36 of the manual!**



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

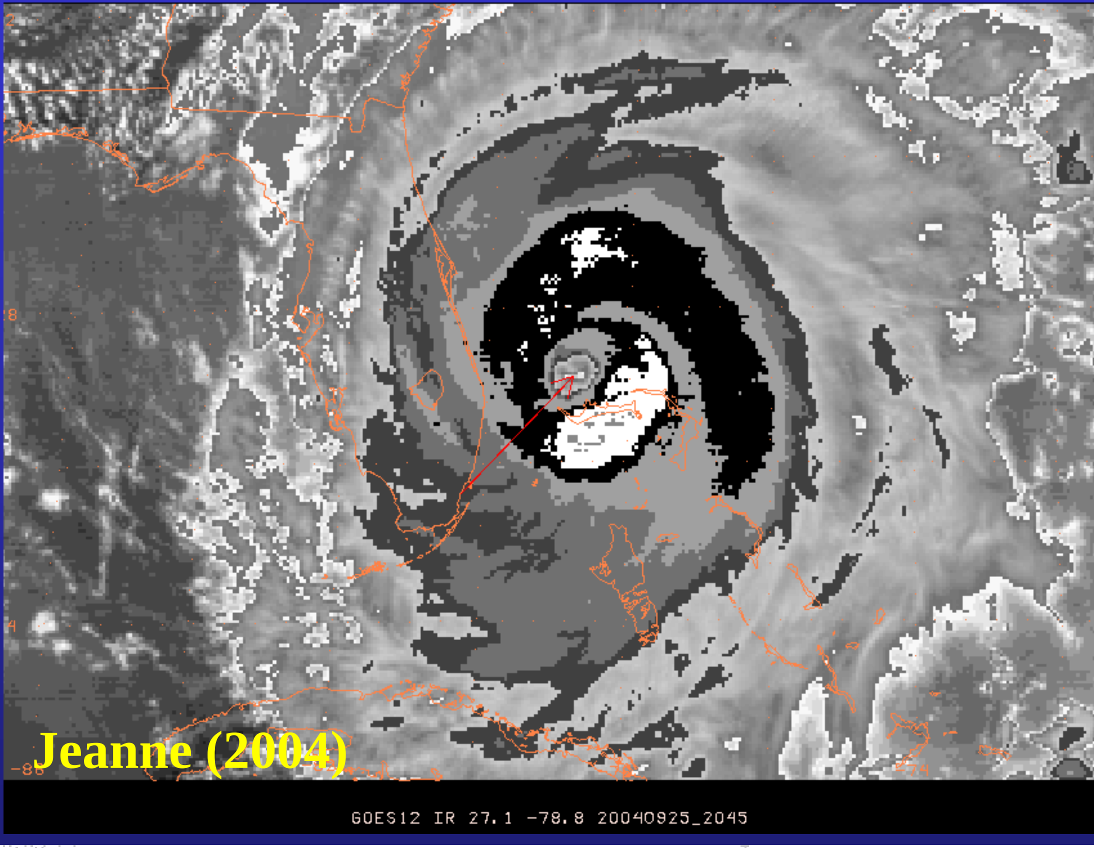
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (WS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| OW eye embdd in B | | | | | | | | B | 5.5 | 0.5 | | | 6.0 | 0.0 | 6.0 | | |

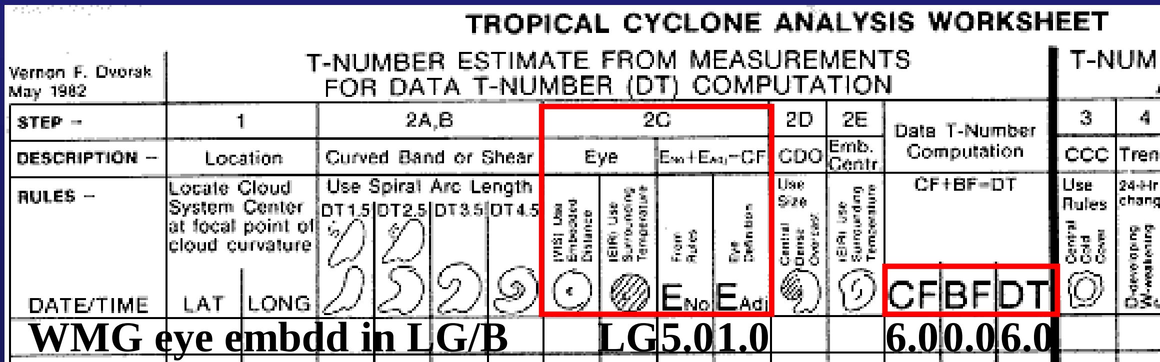
# Step 2C - BD Color Used For Eye Adjustment Can Differ From Color Used For Eye Number

Black (B) completely surrounds the eye. However, the B ring is less than 0.5 degrees thick. So, it cannot be used for the eye number. The eye number uses Light Gray (LG) for a 5.0, while the eye adjustment is determined by a Warm Medium Gray (WMG) embedded in B (+1.0) - CF=6.0



Jeanne (2004)

GOES12 IR 27.1 -78.8 20040925_2045



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

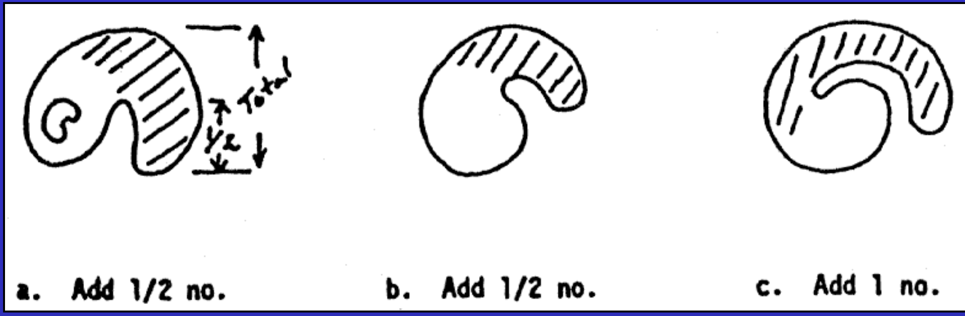
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

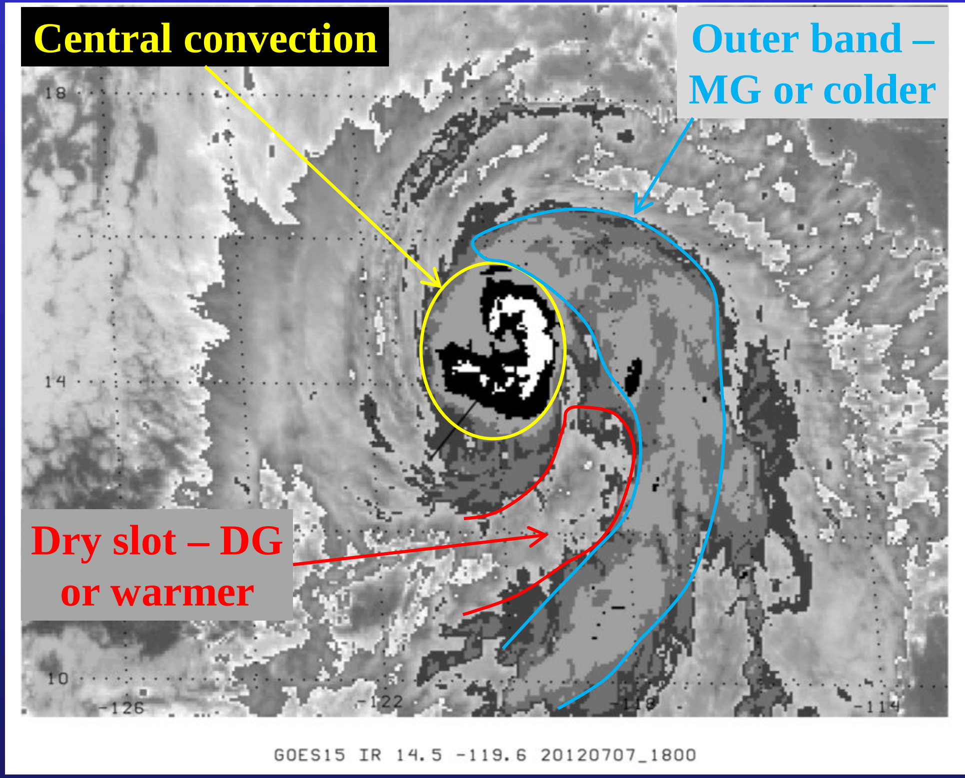
T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| DATE/TIME | LAT | LONG | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| WMG eye embdd in LG/B | | | | | | | | LG | 5.0 | 1.0 | | | 6.0 | 0.0 | 6.0 | | |

# Step 2C - Infrared banding

- **Differs *significantly* from visible banding**
- **Used only when the CF/DT without banding is less than MET**
- **Used only for cloud patterns of CF=4 or more**
- **Band must be MG or colder while dry slot must be DG or warmer**

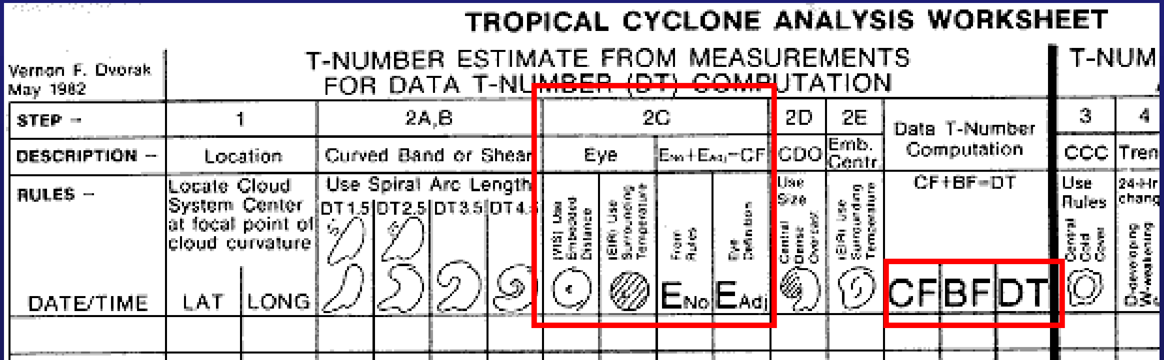




**Daniel (2012) – A potentially eligible IR outer band**

# Notes on Step 2C

- VIS embedded distances are measured from the center of the eye for small eyes and the edge of the eye for large eyes (30 nm/56 km or more in diameter on VIS)
- IR Eye Pattern is the most objective of all Dvorak measurements, but it cannot produce a DT=8.0 without adding banding
- Beware large satellite zenith/viewing angles and not being able to see to the bottom of the eye
- Beware sucker holes!



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

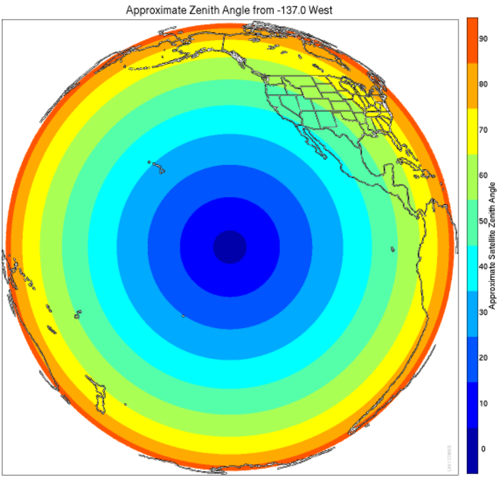
T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

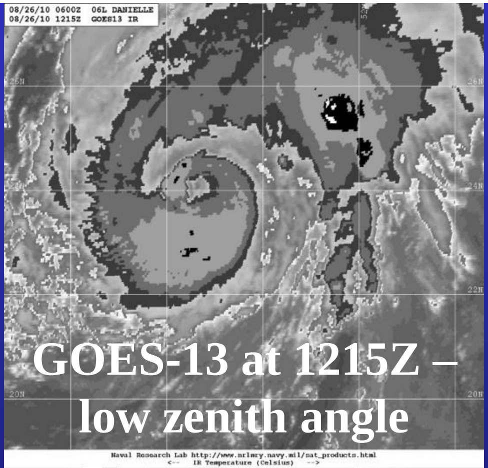
T-NUM

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr chang |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (IR) Use Surrounding Temperature | From Rules | Eye Definition | Central Dense Overcast | (EIR) Use Surrounding Temperature | | | | Central Cold Cover | Developing Weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | | | | | | | | | | | | | |

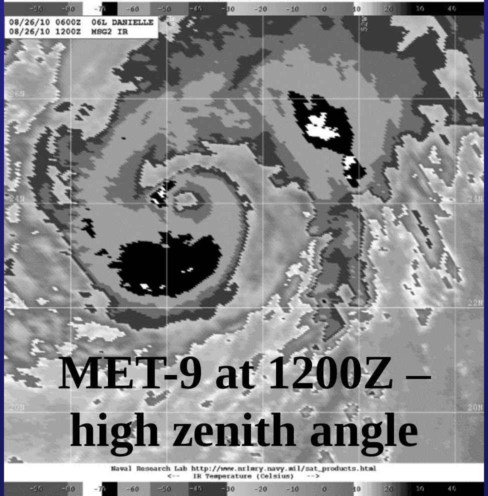
# Problem: Satellite Zenith/Viewing Angle and Cloud Tops

- The satellite zenith/viewing angle of a TC can impact the Dvorak analysis.
- TCs close to the satellite have low zenith/ viewing angles and thus are less of a problem.
- TCs far from the satellite (e. g. near the edge of a full disk scan) are a problem for IR analysis, as IR cloud top temperatures appear too cold.
- High zenith/viewing angles can also make it difficult to see to the bottom of the eye.
- Use the satellite closest to the TC for a Dvorak analysis if at all possible, and use IR DT numbers made at high zenith/viewing angles with caution.
- METEOSAT-9 is at 0W, GOES-East at 75W, and GOES-West at 135W.





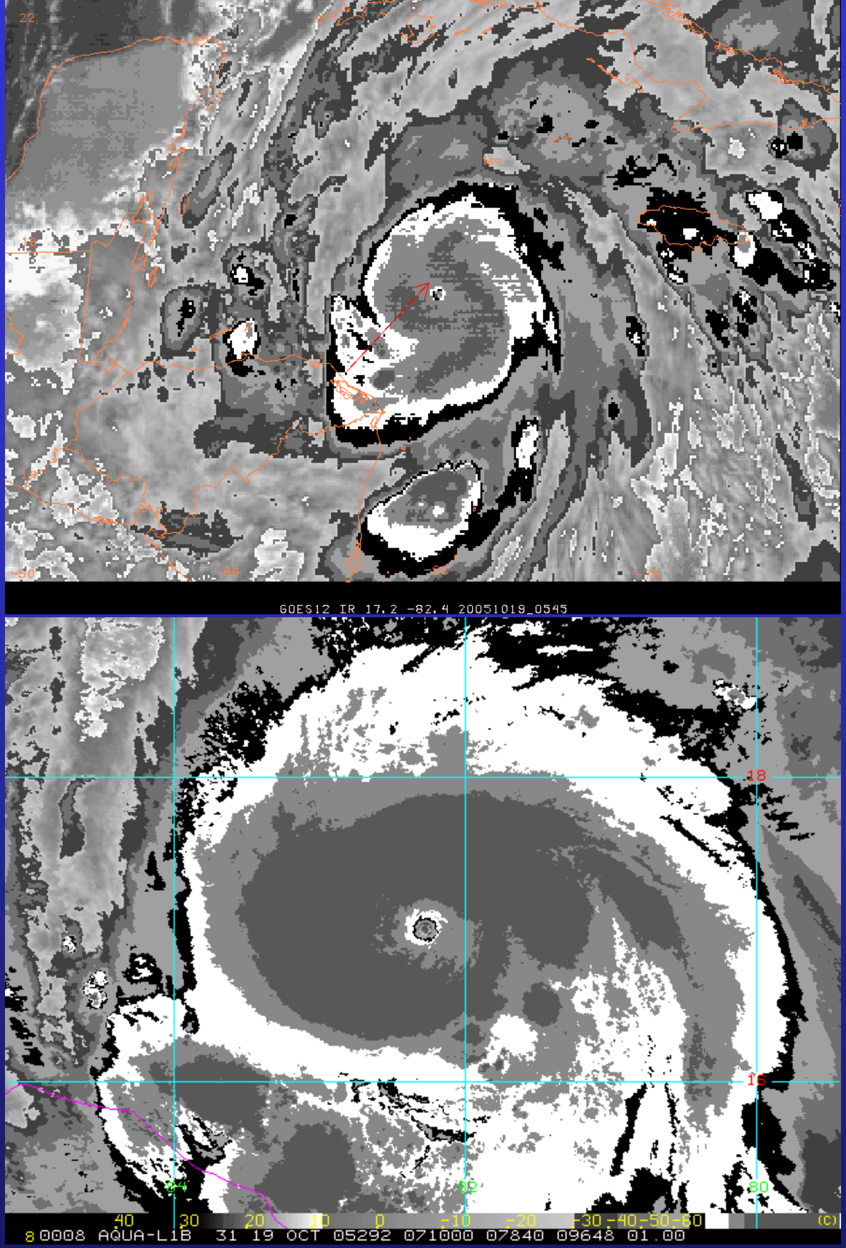
GOES-13 at 1215Z – low zenith angle



MET-9 at 1200Z – high zenith angle

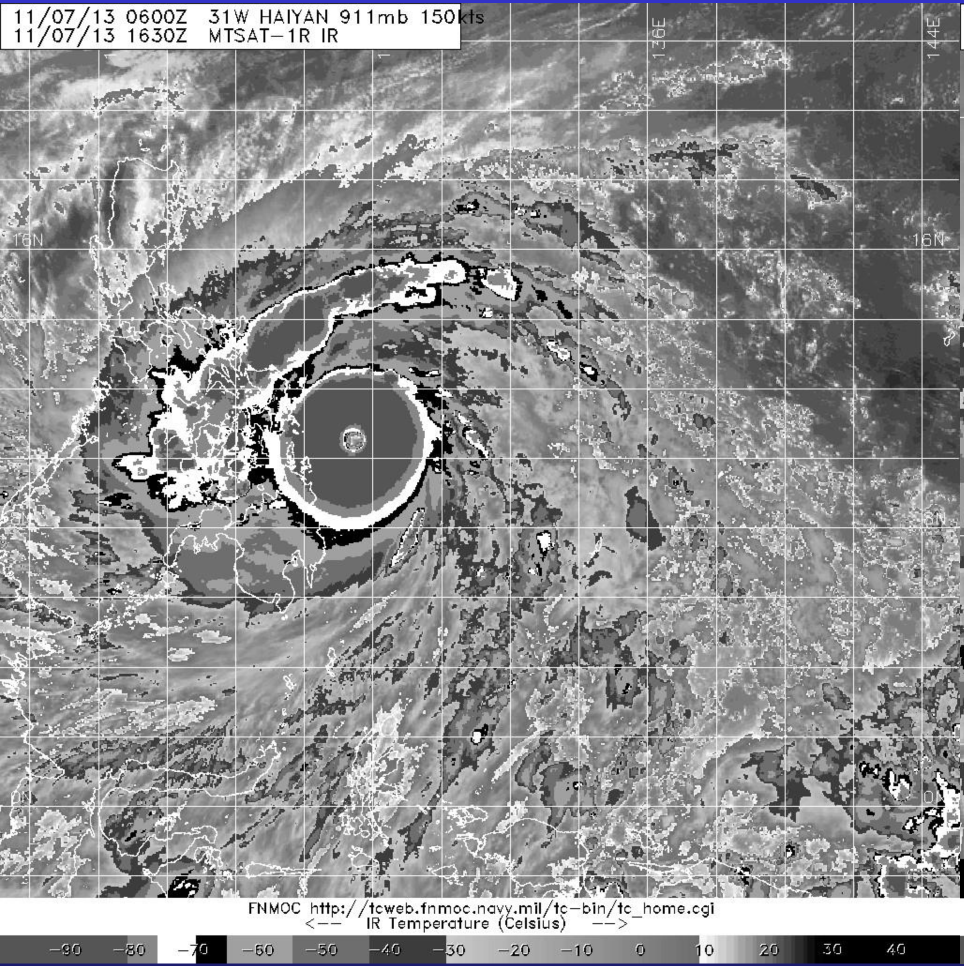
# Problem: Can’t See the Bottom of the Eye

For small eyes (generally less than 10 n mi wide), the satellite may not be able to measure the warmest temperature at the bottom of the eye. This can result in an underestimate of the intensity in both subjective and objective Dvorak techniques.



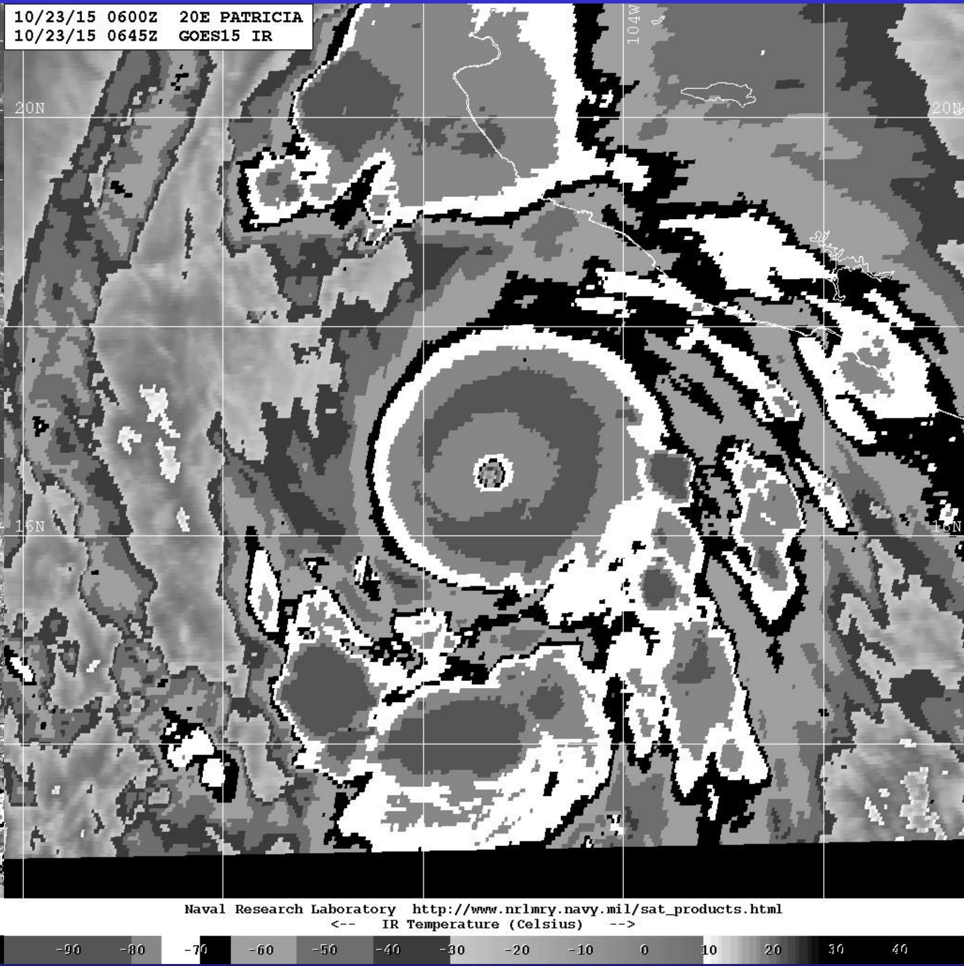
Wilma 2005 - Eye diameter 4 n mi
GOES Eye temperature ~ 0C
NOAA/Aqua Eye temperature ~ +20C

# How strong are these?



**Supertyphoon Haiyan (T8.0)**

**Western North Pacific, 1630Z 7 November 2013**

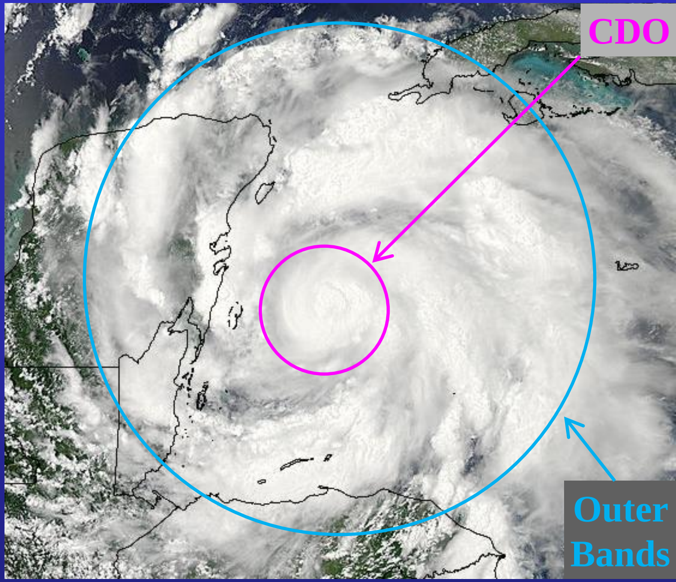


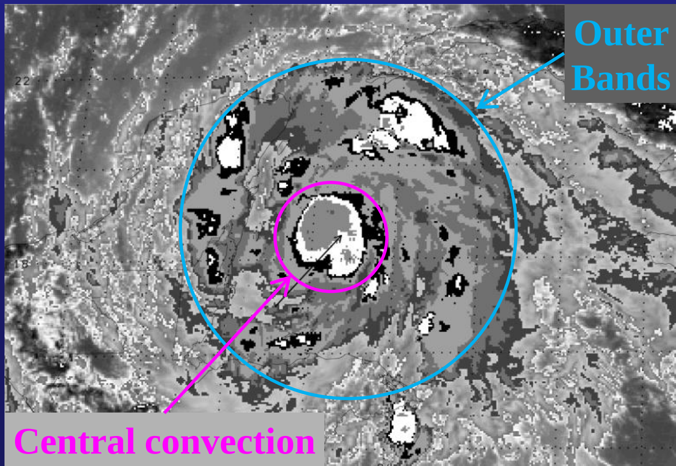
**Hurricane Patricia (180 kt)**

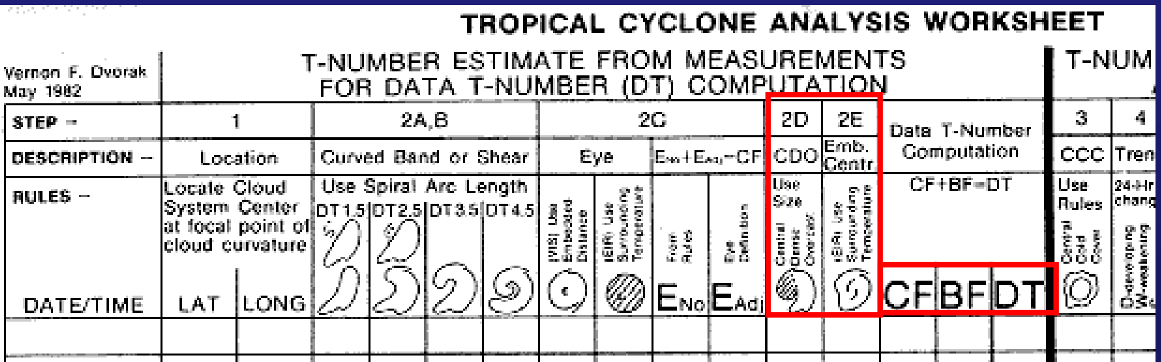
**Eastern North Pacific, 0645Z 23 October 2015**

# Steps 2D and 2E -
# Central Dense Overcast (CDO) and Embedded Center Patterns

- **Patterns are complimentary - CDO uses VIS imagery and Embedded Center uses IR**
- **Both patterns directly produce CF numbers**
- **CDO pattern measures the size of the CDO**
- **Embedded Center pattern measures how far the CSC is embedded into specified colors on the BD curve**
- **All banding rules from Eye patterns apply to CDO and Embedded Center patterns**






TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | | | | | | | | | | | | | |

# Steps 2D and 2E - CDO and Embedded Center Patterns

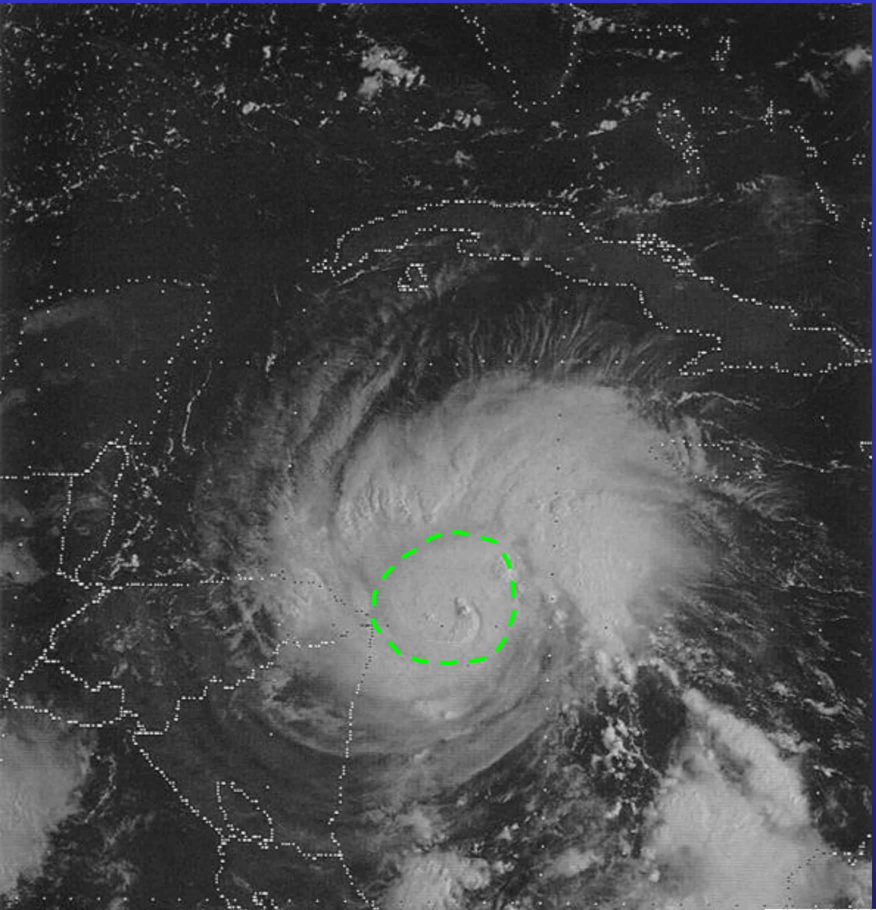
Step 2D - Is the CDO ≥ 0.75 deg wide? If not, go to step 2A or step 4.

| CDO edge is: | Well-defined | | | | Irregular | |
|---|---|---|---|---|---|---|
| Diameter (deg) | ≥2.25 | 1.75 | 1.25 | 0.75 | >1.5 | 1.0-1.5 |
| Central Feature Number (CF) | 5.0 | 4.0 | 3.0 | 2.0 | 3.0 | 2.0 |

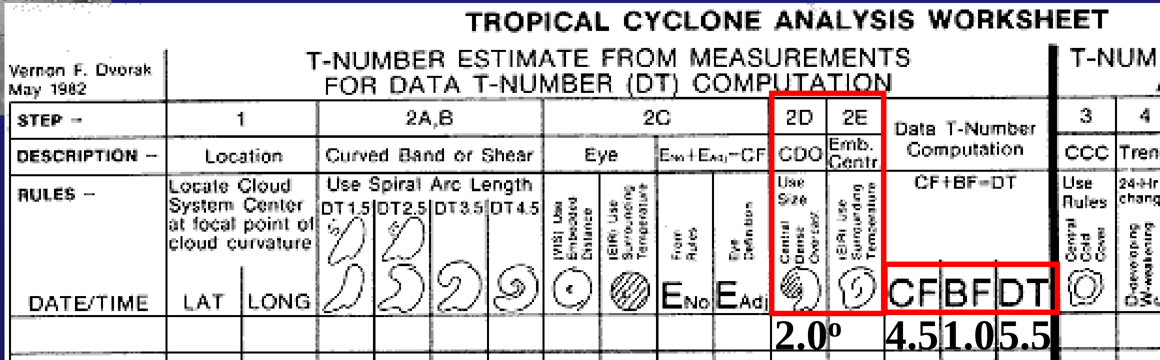
Step 2E - Is the 12 hour old FT ≥ 3.5? If not, go to step 2A or step 4.

| Surrounding BD Color | W or colder | B | LG | MG | DG | OW |
|---|---|---|---|---|---|---|
| Embedded distance (deg) | ≥0.6 | ≥0.6 | ≥0.5 | ≥0.5 | ≥0.4 | ≥0.4 |
| Central Feature Number (CF) | 5.0 | 5.0 | 4.5 | 4.0 | 4.0 | 3.5 |

# Step 2D - Measuring a CDO



The CDO is about 2 deg wide – CF=4.5 + 1.0 for banding around the CDO ➔ DT=5.5



TROPICAL CYCLONE ANALYSIS WORKSHEET

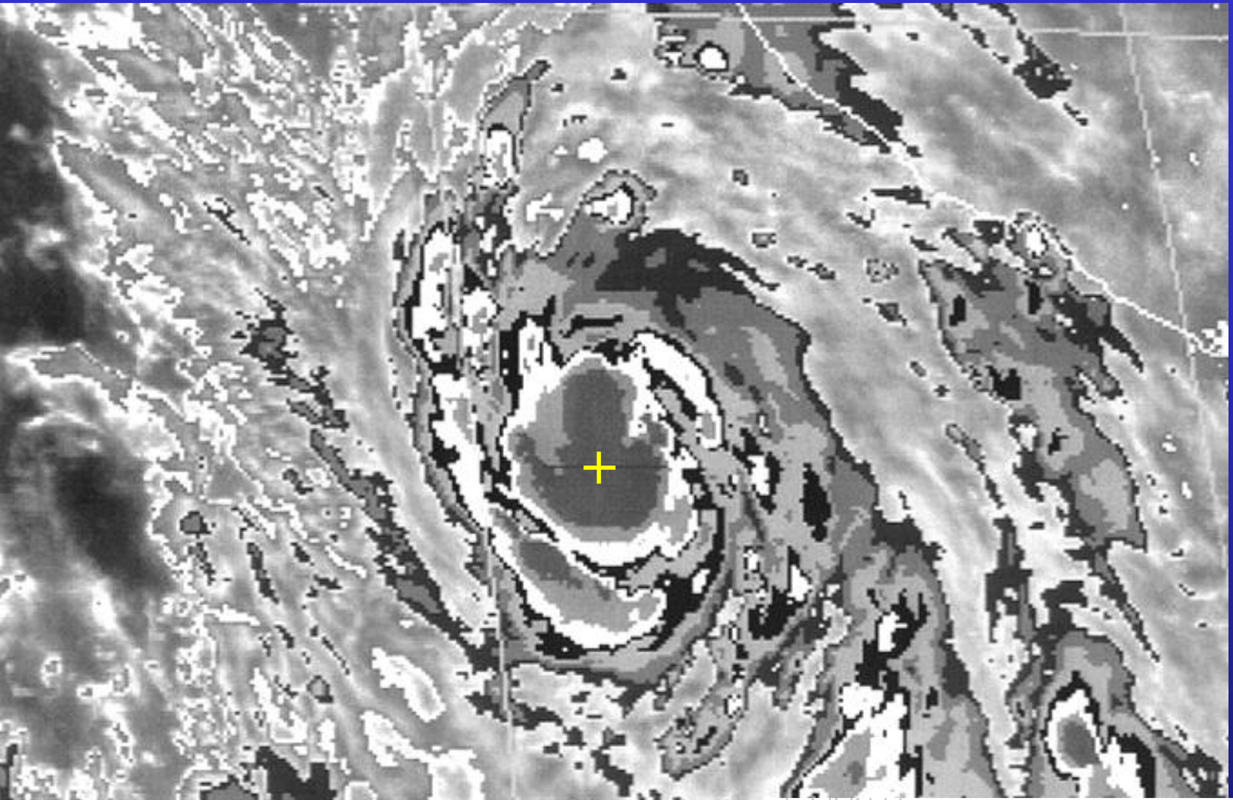
Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

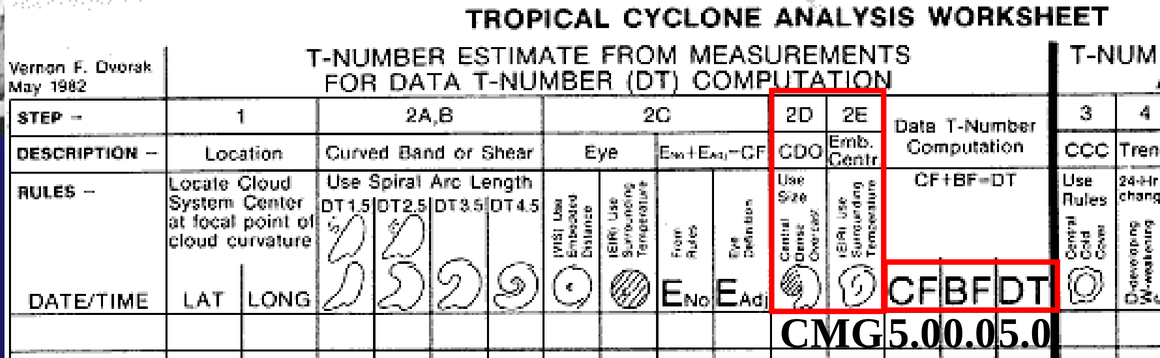
T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP – | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION – | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}-CF$ | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES – | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr chang |
| | | | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Central Dense Overcast | (EIR) Use Surrounding Temperature | | | | Central Cold Cover | Developing Weakening |
| DATE/TIME | LAT | LONG | | | | | | | $E_{No}$ | $E_{Adj}$ | | | CF | BF | DT | | |
| | | | | | | | | | | | 2.0º | | 4.5 | 1.0 | 5.5 | | |

# Step 2E - Measuring an Embedded Center



CSC embedded in CMG - DT=5.0



TROPICAL CYCLONE ANALYSIS WORKSHEET

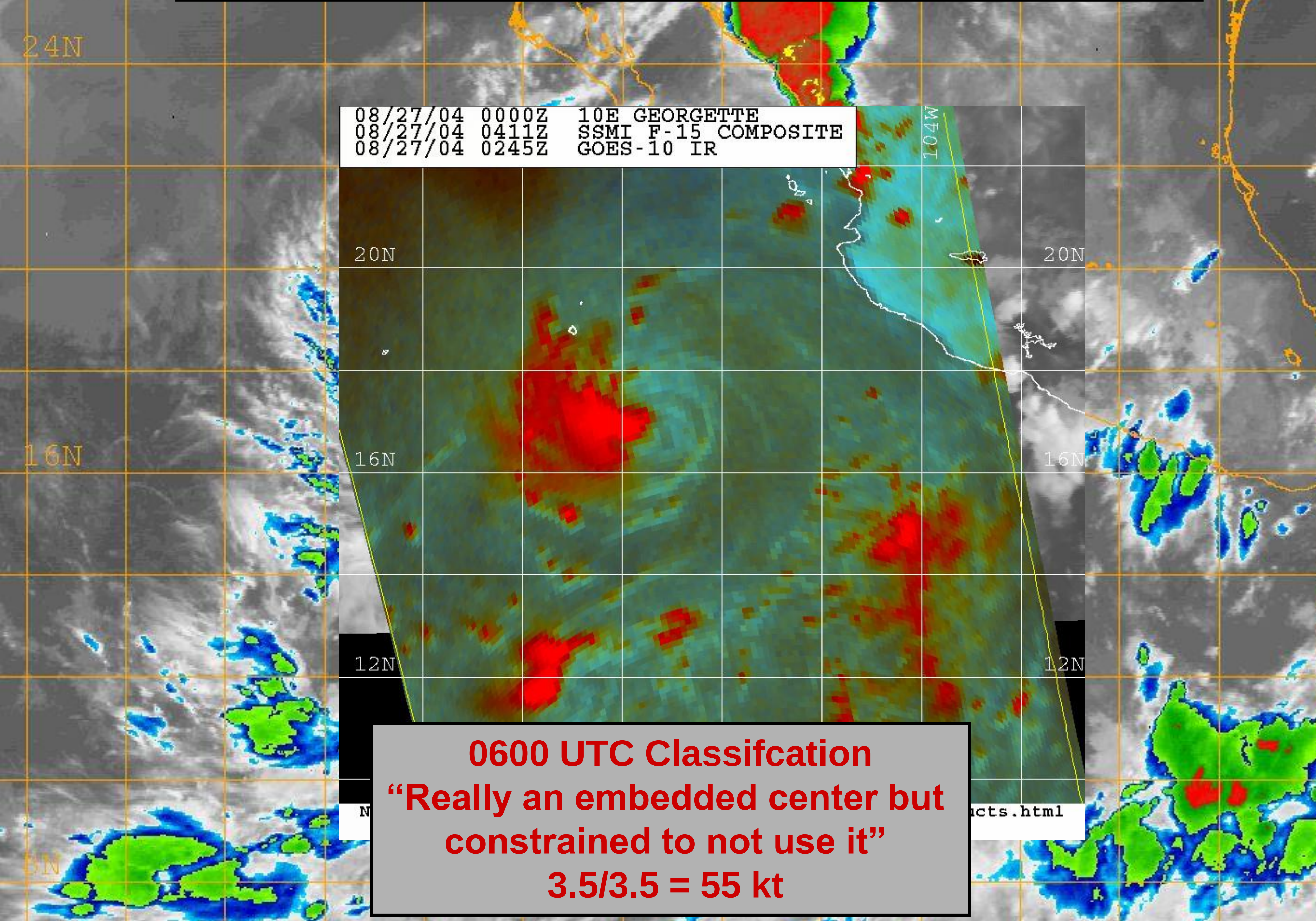
Vernon F. Dvorak
May 1982

T-NUMBER ESTIMATE FROM MEASUREMENTS
FOR DATA T-NUMBER (DT) COMPUTATION

T-NUM

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 |
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | E<sub></sub>No+EAdj−CF | | CDO | Emb. Centr | | | | CCC | Tren |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | From Rules | Eye Definition | Use Size<br>Central Dense Overcast | (EIR) Use Surrounding Temperature | CF+BF=DT | | | Use Rules<br>Central Cold Cover | 24-Hr chang<br>Developing Weakening |
| | | | DT 1.5 | DT2.5 | DT3.5 | DT4.5 | | | | | | | | | | | |
| DATE/TIME | LAT | LONG | | | | | | | ENo | EAdj | | | CF | BF | DT | | |
| | | | | | | | | | | | CMG | | 5.0 | 0.0 | 5.0 | | |

# 0430 UTC 27 August 2004 GOES-10 IR TS Georgette



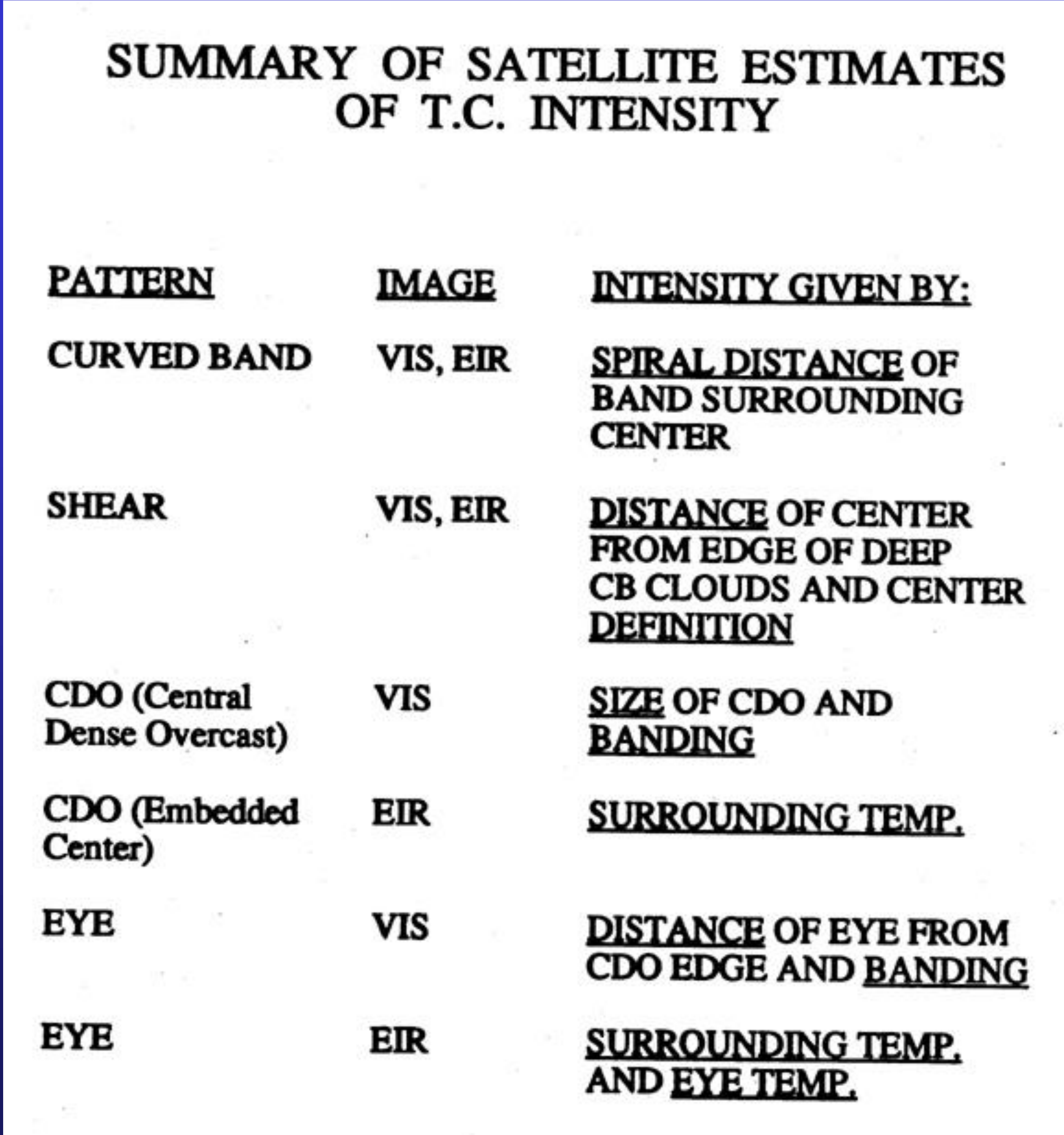
**0600 UTC Classifcation**
**“Really an embedded center but constrained to not use it”**
**3.5/3.5 = 55 kt**

# Notes on Steps 2D and 2E

- **Edge of CDO is often subjective**
- **You can interpolate between the CDO CF numbers when appropriate**
- **For an elliptical CDO, the CDO size is the average of the sizes of the long and short axes of the ellipse.**
- **Embedded Center pattern can only be used when the 12 hr old FT is 3.5 or greater as otherwise it can produce unrealistically high intensity estimates**
- **Embedded Center pattern is the most uncertain of all Dvorak measurements - where the classifier puts the CSC makes a big difference in the intensity estimate**
- ***When available and appropriate, use of VIS CDO is preferable to use of IR embedded center***

# Pattern Recognition Exercise!

# To summarize the cloud pattern types...

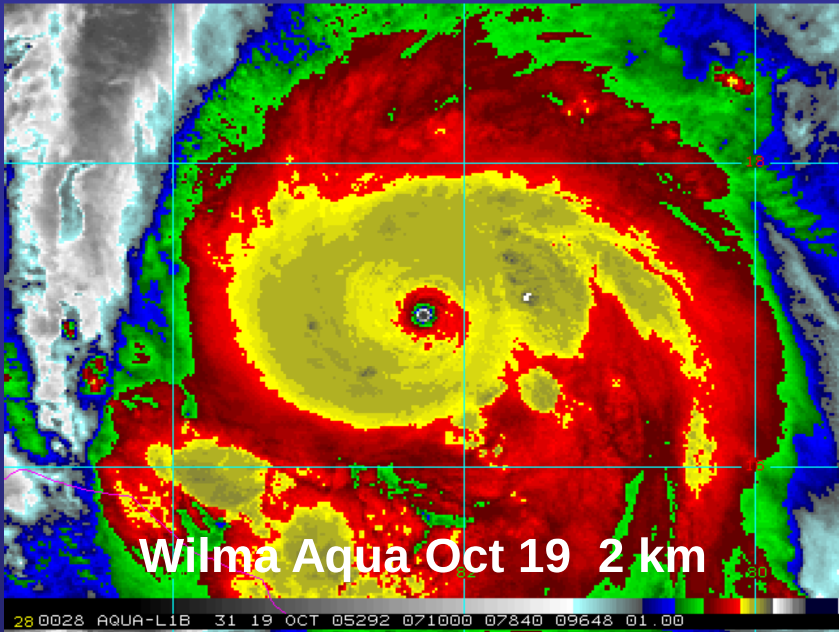


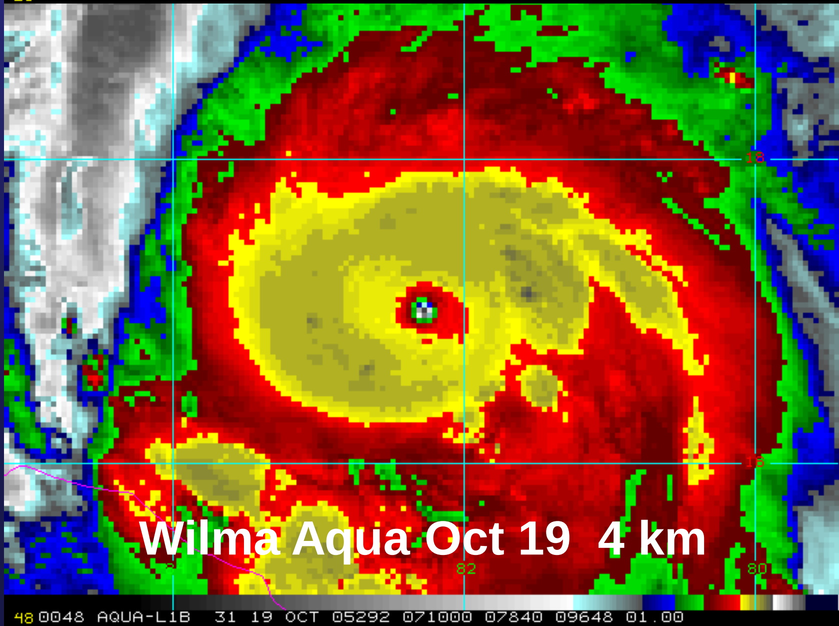
## SUMMARY OF SATELLITE ESTIMATES OF T.C. INTENSITY

| PATTERN | IMAGE | INTENSITY GIVEN BY: |
|---|---|---|
| CURVED BAND | VIS, EIR | SPIRAL DISTANCE OF BAND SURROUNDING CENTER |
| SHEAR | VIS, EIR | DISTANCE OF CENTER FROM EDGE OF DEEP CB CLOUDS AND CENTER DEFINITION |
| CDO (Central Dense Overcast) | VIS | SIZE OF CDO AND BANDING |
| CDO (Embedded Center) | EIR | SURROUNDING TEMP. |
| EYE | VIS | DISTANCE OF EYE FROM CDO EDGE AND BANDING |
| EYE | EIR | SURROUNDING TEMP. AND EYE TEMP. |

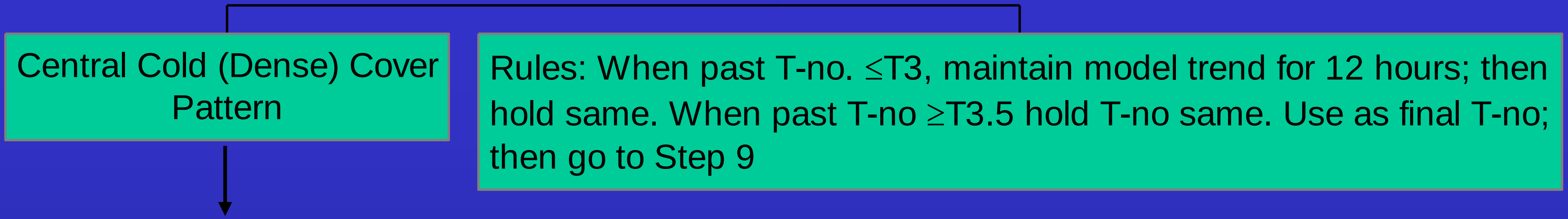
# Data-T Numbers in the ABI/AHI Era

- **Measurements of most of the Dvorak cloud patterns are relatively insensitive to the higher resolution of the new imagers on the GOES-R/ Himawari satellites.**
- **Infrared eye patterns could seen changes in Data-T numbers caused by 1) seeing warmer temperatures in the eye, and 2) seeing less uniform cloud tops surrounding the eye.**
- **In most cases, the Data-T numbers will change little, although some cases could see changes of 0.5 T-numbers.**
- ***There is a need to develop a Dvorak-like algorithm for the more advanced ABI/AHI data!***



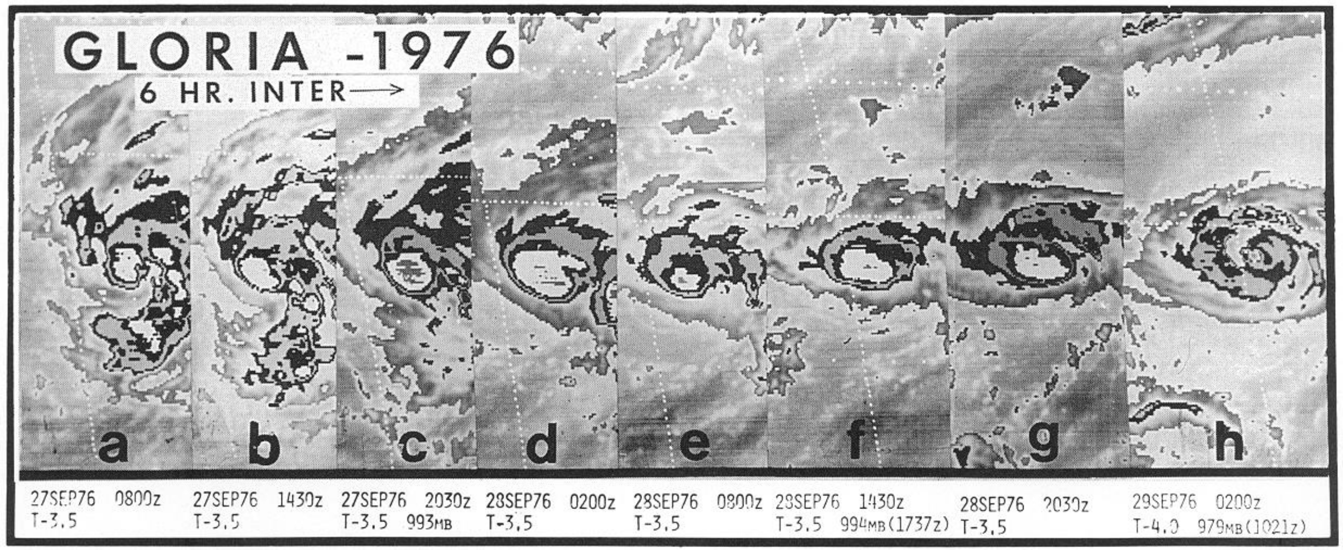


# Step 3 - Central Cold Cover Pattern

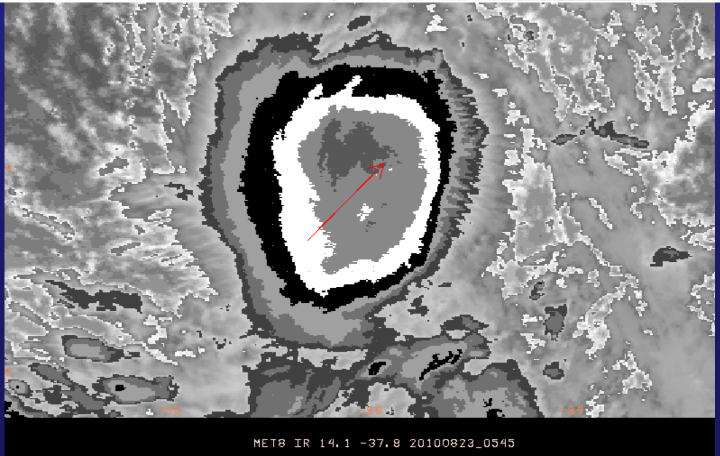


Central Cold (Dense) Cover Pattern

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



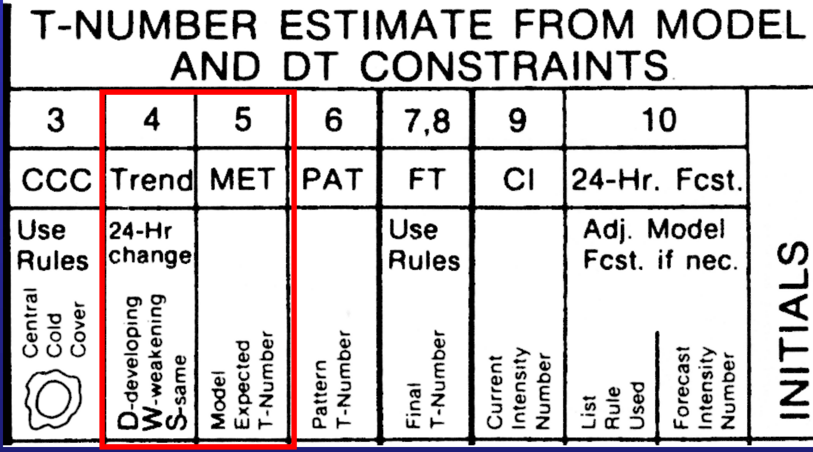
- Also known as “bursting” pattern
- Can resemble shear or CDO/embedded center patterns



Danielle (2010) – a likely CCC pattern

# Steps 4 and 5 - Determine 24 hr Trend and Model Expected T-Number (MET)

- **The Dvorak Technique employs a conceptual model of TC growth and decay rates over 24 hr periods**
- **24 hr comparisons avoid the diurnal convective variations observed in TC cloud patterns**
- **For trend purposes, <u>always</u> use 24 hr comparisons even though intensity estimate are made more frequently (e. g. every 6 hr)**
- **24 hr trends are reported as <u>D</u>eveloping, <u>W</u>eakening, or <u>S</u>teady**



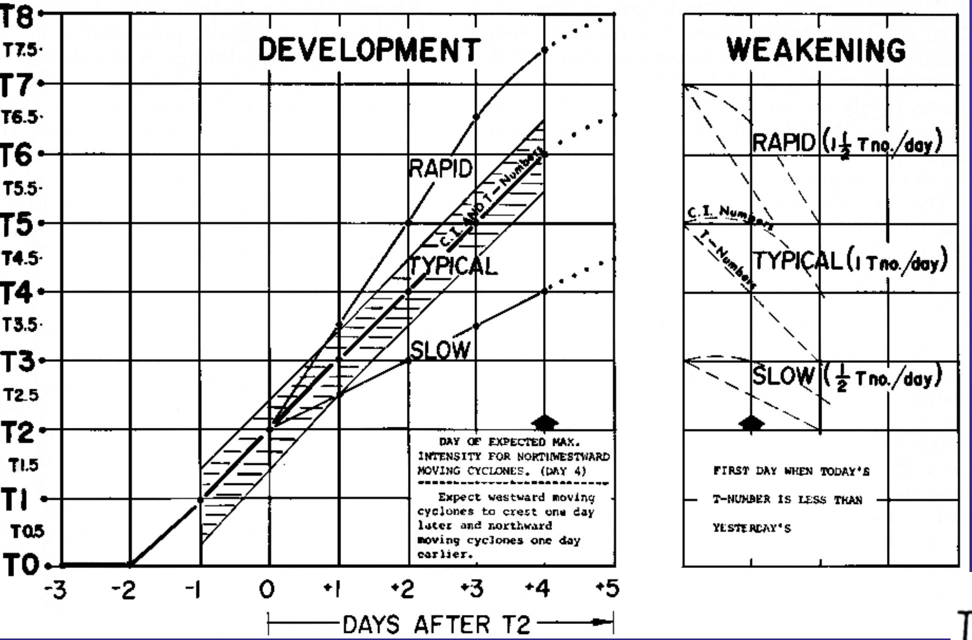
T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | INITIALS |
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | |
| Central Cold Cover | D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |

# Step 4 - Determine 24 hr Trend

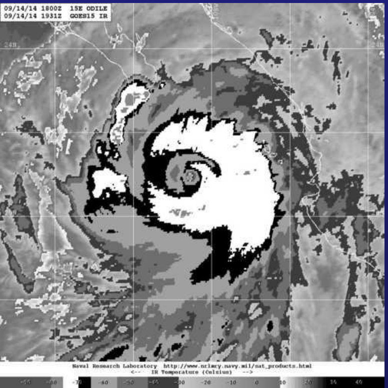
| Developing | Weakening | Steady |
|---|---|---|
| Increased convection near CSC (larger or colder CDO) | Decreased convection near CSC (smaller or warmer CDO) | No noticeable 24 hr change |
| Increased curved banding (primary band or bands around the CDO) | Decreased curved banding | Both developing and weakening signs present (mixed signals) |
| Eye forms, or becomes warmer, or more distinct | Eye disappears, or becomes cooler, or less distinct | CCC in a cyclone of T3.5 or greater or CCC for 12 hr or more in a weaker cyclone |
| Exposed center closer to overcast | Exposed center further from overcast or covered center becomes exposed | |
| Increased curvature of low clouds near CSC | Decreased curvature of low clouds near CSC | |

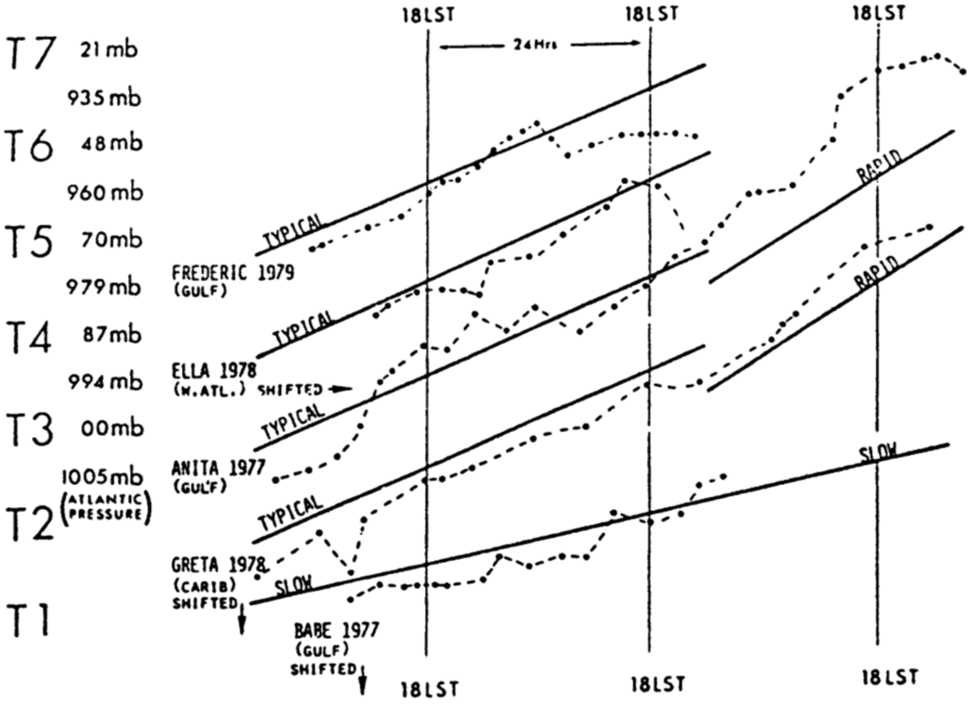
# Dvorak Model Development Curves



In the Dvorak conceptual model, 'normal' strengthening or weakening is 1 T-number/day. Rapid changes are 1.5 T-numbers per day, while slow changes are 0.5 T-numbers/day.

Note: Eyewall replacement cycles are <u>not</u> part of the Dvorak conceptual model.

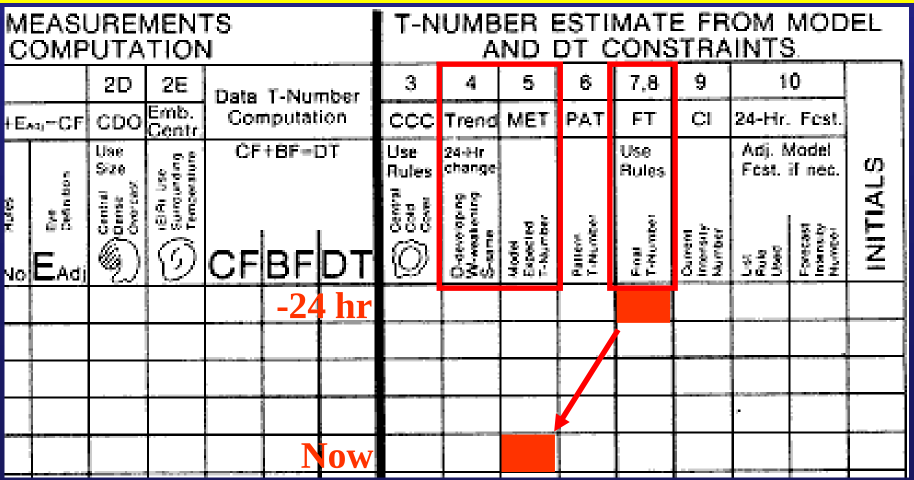




# Step 5 - Model Expected T-Number

- The MET is a first guess estimate of the intensity based on the 24 hr old Final T-Number and the current determined 24 hr trend
- For a Steady trend, the MET = the 24 hr old FT
- The MET for first classification is 1.0

| | Developing | Weakening |
|---|---|---|
| Rapid | MET=24 hr old FT+1.5 | MET=24 hr old FT-1.5 |
| Normal | MET=24 hr old FT+1.0 | MET=24 hr old FT-1.0 |
| Slow | MET=24 hr old FT+0.5 | MET=24 hr old FT-0.5 |



MEASUREMENTS COMPUTATION

T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS.

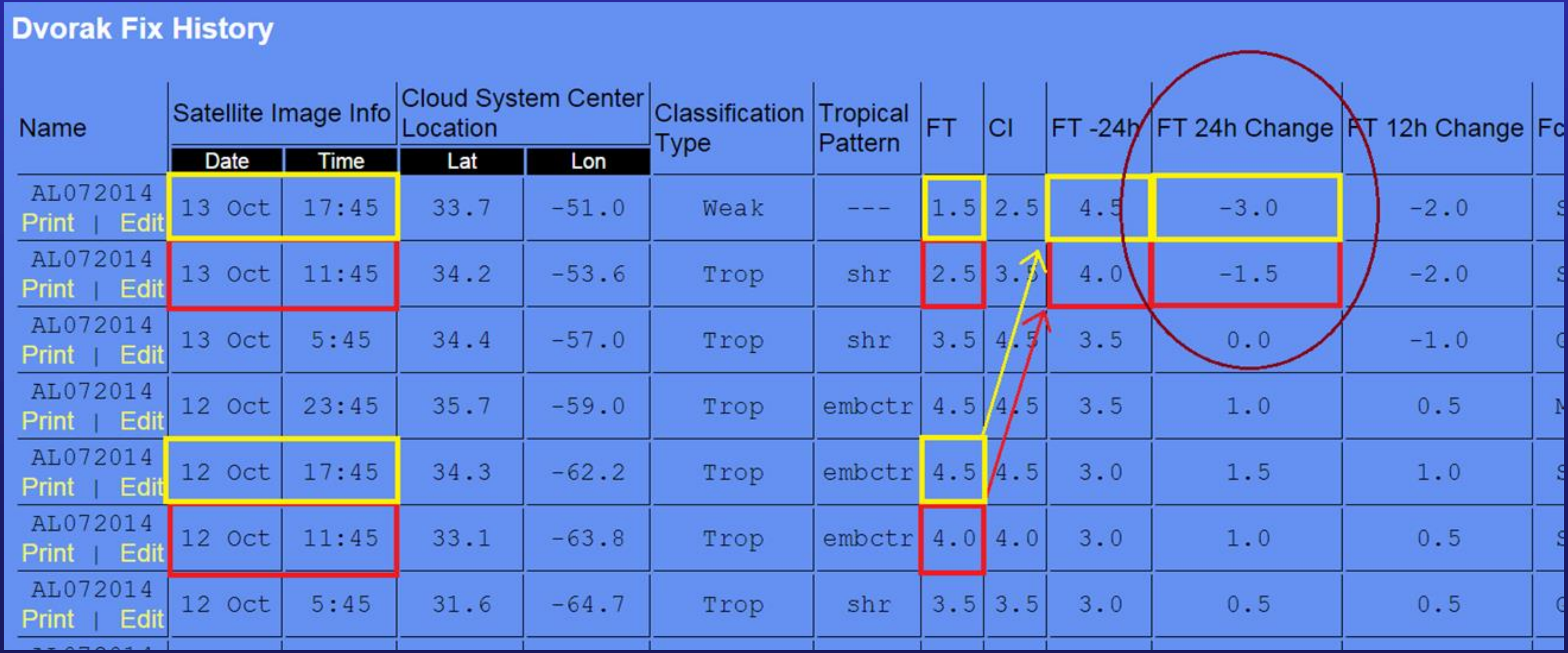
| | | 2D | 2E | Data T-Number Computation | | | 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| +E<sub></sub> | | | | | | | | | | | | | | | |

# Step 5 - Model Expected T-Number Rapid or Slow Changes

- **Two consecutive previous Dvorak measurements of rapid or slow development/weakening are needed to establish rapid or slow 24 hr changes**
  - *Look at the previous two FT values and compare them to the respective FT values from 24 hours prior*
  - *If the difference between both of these values is more (less) than 1.0, then you have rapid (slow) development/weakening (add the +/- to the D or W)*
  - *This does not count the measurement your currently making*
- **Or, one previous Dvorak measurement and signs of strong intensification or weakening (Step 10)**

# Step 5 - Model Expected T-Number Rapid or Slow Changes

**Example: For the upcoming fix for 00Z/14 Oct 2014, note there are two consecutive 24 hour changes in the column labeled "FT 24h Change". If the 24 hour trend for the 00Z /14 Oct fix is weakening, the prior trends justify a W+, since there are two consecutive 24 hr changes for FT that are more than 1.0.**



**Dvorak Fix History**

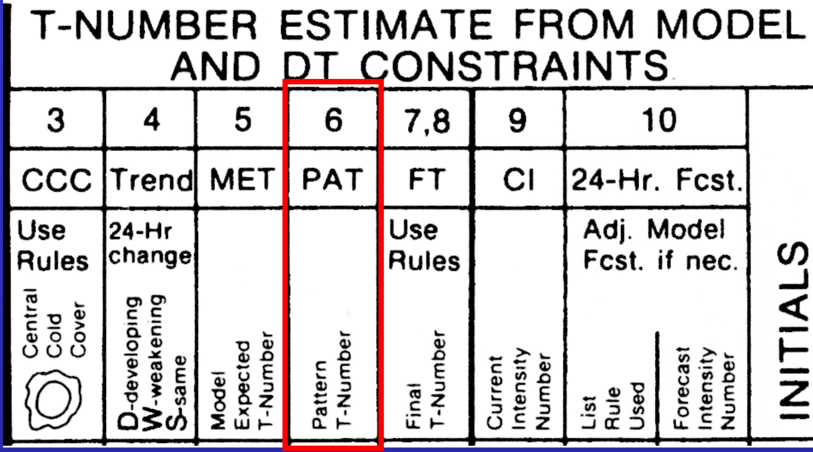
| Name | Satellite Image Info | | Cloud System Center Location | | Classification Type | Tropical Pattern | FT | CI | FT -24h | FT 24h Change | FT 12h Change | Fc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Time | Lat | Lon | | | | | | | | |
| AL072014<br>Print \| Edit | 13 Oct | 17:45 | 33.7 | -51.0 | Weak | --- | 1.5 | 2.5 | 4.5 | -3.0 | -2.0 | |
| AL072014<br>Print \| Edit | 13 Oct | 11:45 | 34.2 | -53.6 | Trop | shr | 2.5 | 3.5 | 4.0 | -1.5 | -2.0 | |
| AL072014<br>Print \| Edit | 13 Oct | 5:45 | 34.4 | -57.0 | Trop | shr | 3.5 | 4.5 | 3.5 | 0.0 | -1.0 | |
| AL072014<br>Print \| Edit | 12 Oct | 23:45 | 35.7 | -59.0 | Trop | embctr | 4.5 | 4.5 | 3.5 | 1.0 | 0.5 | |
| AL072014<br>Print \| Edit | 12 Oct | 17:45 | 34.3 | -62.2 | Trop | embctr | 4.5 | 4.5 | 3.0 | 1.5 | 1.0 | |
| AL072014<br>Print \| Edit | 12 Oct | 11:45 | 33.1 | -63.8 | Trop | embctr | 4.0 | 4.0 | 3.0 | 1.0 | 0.5 | |
| AL072014<br>Print \| Edit | 12 Oct | 5:45 | 31.6 | -64.7 | Trop | shr | 3.5 | 3.5 | 3.0 | 0.5 | 0.5 | |

# Notes on steps 4 and 5

- The trend for step 4 is determined by examining satellite images 24 hours apart.
- The trend for the initial classification is always a normal D.
- You need at least 24 hours of Dvorak classifications to change the development trend. The first 18 hours after the initial T1 are always a normal D.
- Changes in the development rate for step 5 from D to D- or D+ (or W to W- or W+) need to use the technique rules. Just because you think you are on a different development rate does not allow you to change it arbitrarily!

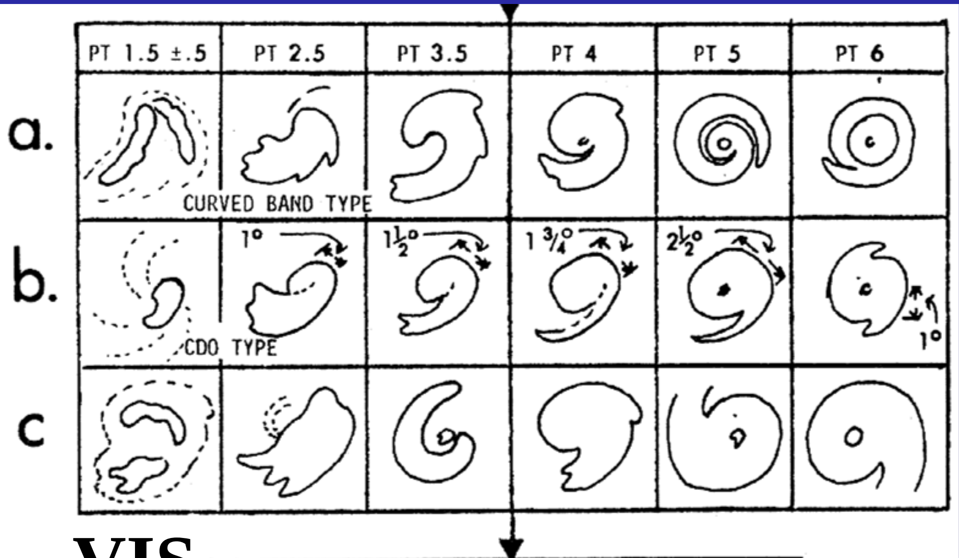
# Step 6 - Pattern T-Number (PT or PAT)

- Choose the Pattern T-number by comparing the cyclone cloud pattern to the diagrams on the flow charts
- PATs above T6 require extrapolation



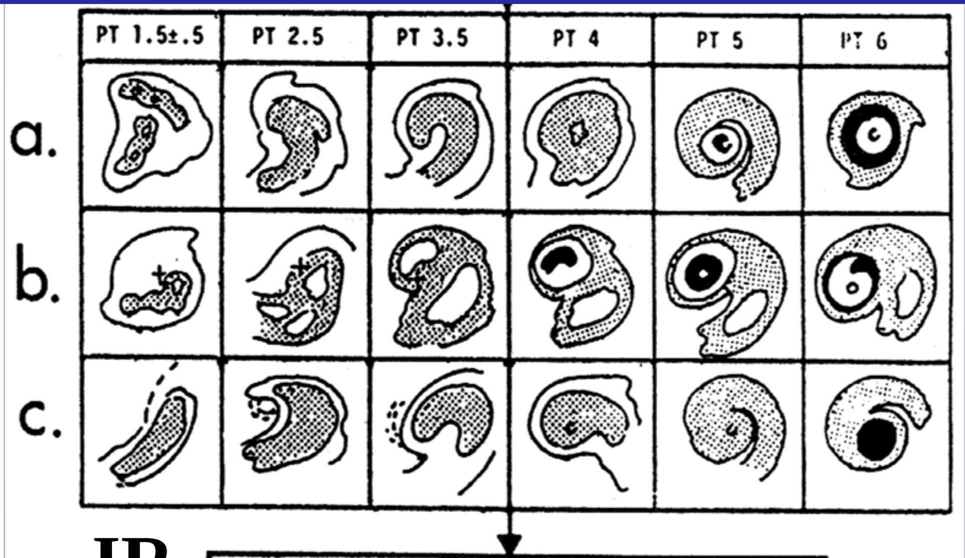
T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | |
| Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | |
| Central Cold Cover | D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used<br>Forecast Intensity Number | INITIALS |



**VIS**

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

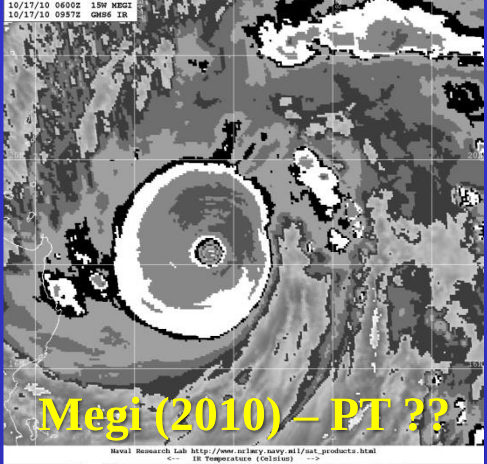


**IR**

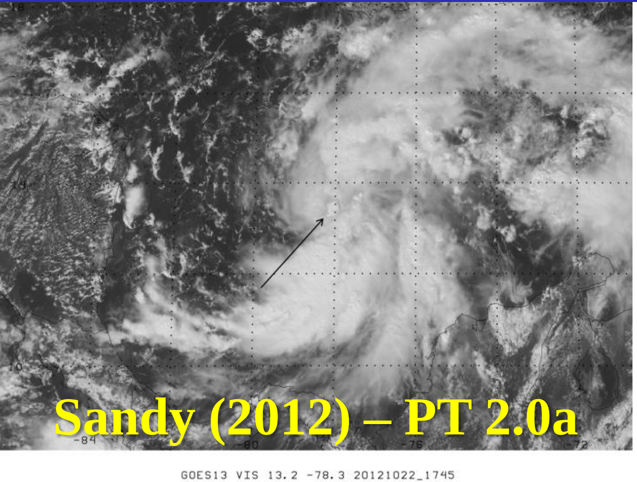
*When hatched part of these patterns is white or colder, add .5 to pattern number.

If the PT is 1 or more T-numbers from the MET, check your work!

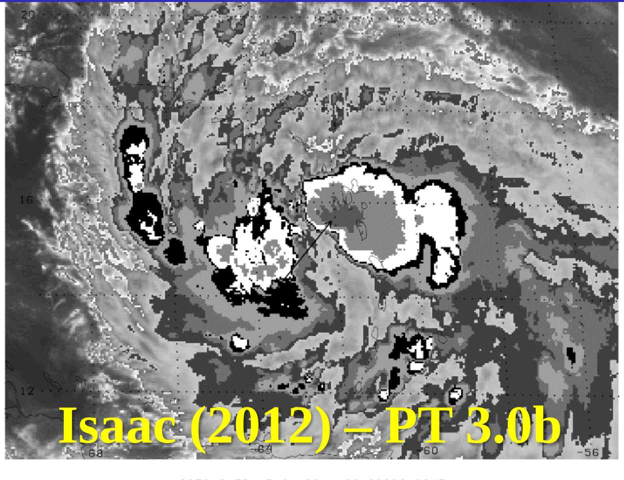
# Step 6 - Pattern T-Number (PT or PAT)



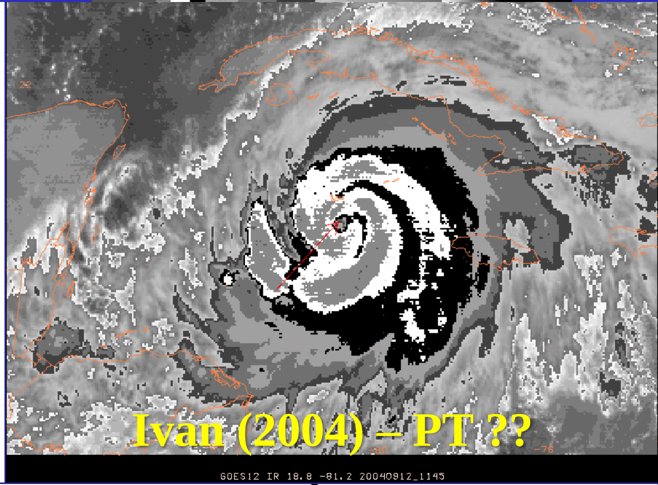
Megi (2010) – PT ??



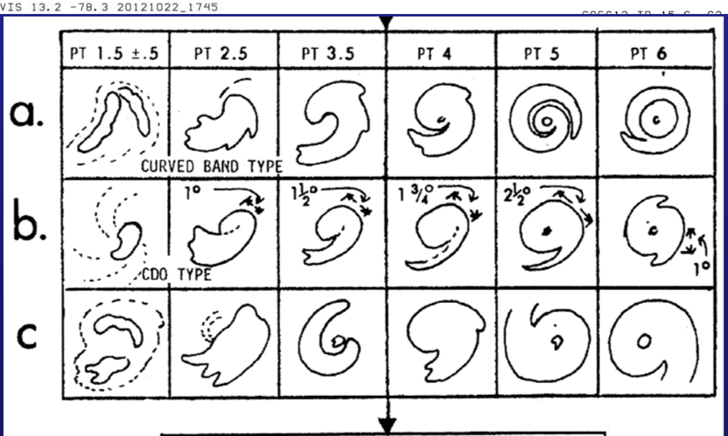
Sandy (2012) – PT 2.0a



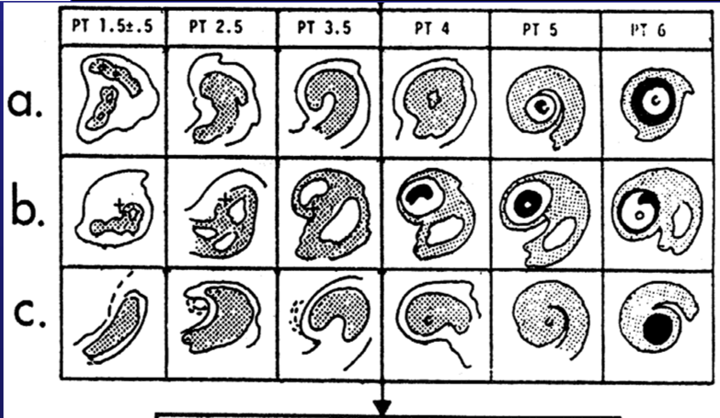
Isaac (2012) – PT 3.0b



Ivan (2004) – PT ??



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

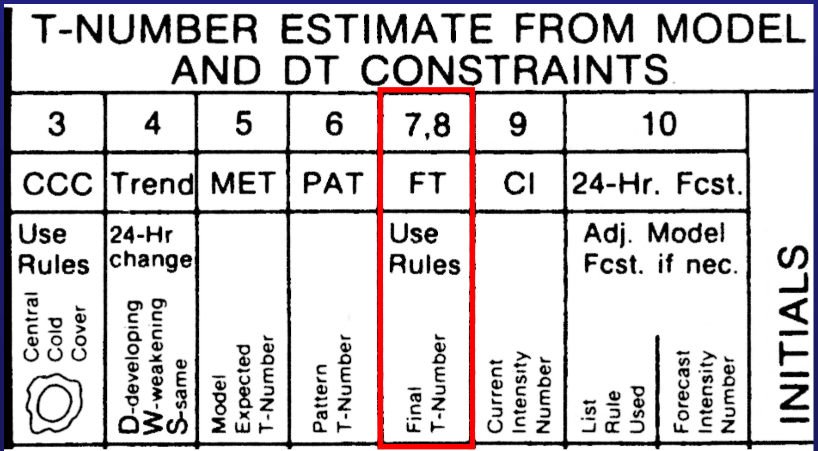


*When hatched part of these patterns is white or colder, add .5 to pattern number.

# Pattern and Trend Exercise!

# Step 7 - Final T-Number (FT)

- Choose the FT from the DT, PT and MET:
  - Use DT from Step 2 when cloud features are clear-cut
  - Use PT from Step 6 when DT is not clear and when PT is different from MET
  - For all other cases, use the MET from step 5
- Beware constraints! (Step 8)



T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

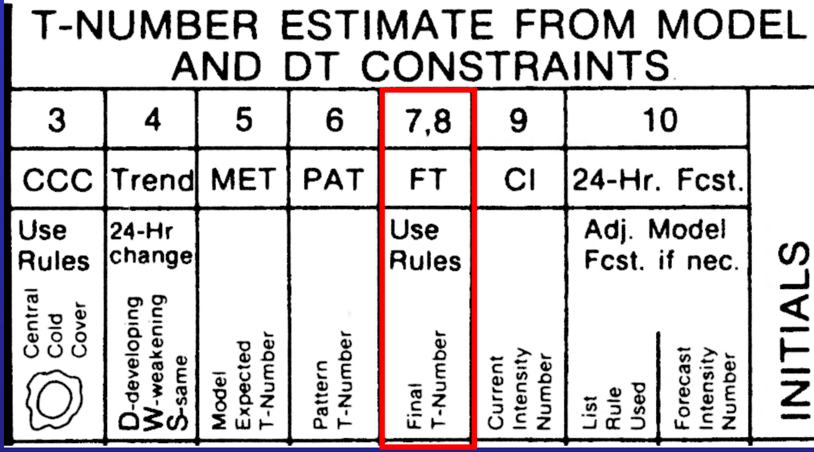
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | INITIALS |
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | |
| Central Cold Cover | D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |

# What comprises a clear-cut DT?

- What comprises clear cut:
  - An unambiguous cloud pattern measurement. For example, an infrared eye measurement is often considered clear cut.
  - Measurements using multiple cloud pattern types that give the same DT
- What does not:
  - Ambiguous or hard to measure/interpret cloud pattern measurements. For example, shear pattern measurements are often not clear cut.
  - Measurements using multiple cloud pattern types that give different DTs

# Step 8 - FT Constraints

1. **Initial classification must be T1 or T1.5**
2. **During first 24 hours of development, FT cannot be lowered at night**
3. **24 hr after initial T1, FT must be ≤ 2.5**
4. **Modified FT limits (next slide)**
5. **FT must = MET ± 1**



T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | |
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | INITIALS |
| Central Cold Cover | D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |

**Note: The CI <u>never</u> constrains the FT!**

# Step 8 - FT Number Change Limits

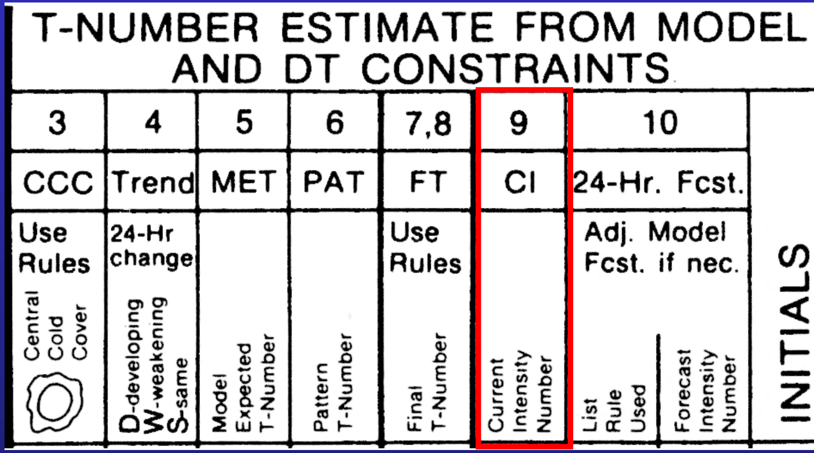
For early development: 0.5 T-numbers over 6 hr

<table>
<tr><th>Original FT Constraints for storms with T≥4.0 (Dvorak):</th><th>Modified FT Constraints now used for developing storms above T1.5 (24 hr or more after the initial T1) (Pike NHC study):</th></tr>
<tr><td colspan="2">1.0 T-numbers over 6 hr<br>1.5 T-numbers over 12 hr<br>2.0 T-numbers over 18 hr<br>2.5 T-numbers over 24 hr</td></tr>
</table>

These are the maximum changes in FT number allowed over the given time periods.

# Step 9 - Current Intensity Number (CI)

- **During the initial development and some stages of re-development, CI=FT**
- **For weakening or re-developing systems, hold the CI to the highest FT during the preceding 12 hr, but <u>never</u> more than 1.0 above the current FT**
- **CI is never < FT!**



T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | |
| Use Rules<br>Central Cold Cover | 24-Hr change<br>D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Use Rules<br>Final T-Number | Current Intensity Number | Adj. Model Fcst. if nec.<br>List Rule Used<br>Forecast Intensity Number | INITIALS |

# Step 9 - CI Examples

## (6 hr intervals)

| FT/CI | FT/CI | FT/CI | FT/CI |
|---|---|---|---|
| 1.5/1.5 | 6.0/6.0 | 6.0/6.0 | 5.5/5.5 |
| 2.0/2.0 | 5.5/6.0 | 5.0/6.0 | 5.0/5.5 |
| 2.5/2.5 | 4.5/5.5 | 4.5/5.5 | 4.5/5.5 |
| 3.0/3.0 | 4.0/5.0 | 4.5/5.0 | 3.5/4.5 |
| 3.5/3.5 | 3.5/4.5 | 4.5/4.5 | 4.0/4.5 |
| 4.0/4.0 | 3.0/4.0 | 4.0/4.5 | 4.5/4.5 |
| 4.5/4.5 | 2.0/3.0 | 3.5/4.5 | 5.0/5.0 |
| Steady rapid development | Accelerating weakening | Interrupted weakening | Weakening, then re-development |

# Step 9 - What's wrong here?

## (6 hr intervals)

| FT/CI | FT/CI | FT/CI | FT/CI |
|---|---|---|---|
| 1.0/1.0 | 6.0/6.0 | 6.0/6.0 | 5.5/5.5 |
| 2.5/2.5 | 5.0/6.0 | 5.5/6.0 | 5.0/5.5 |
| 3.5/3.5 | 4.5/6.0 | 4.5/5.5 | 5.0/5.5 |
| 5.0/5.0 | 4.0/5.0 | 4.5/5.5 | 5.0/5.5 |
| 6.5/6.5 | 3.5/4.5 | 4.5/5.5 | 5.0/5.5 |
| 7.0/7.0 | 2.5/4.0 | 4.0/5.0 | 5.0/5.5 |
| 7.5/7.5 | 2.0/3.5 | 3.5/4.5 | 5.0/5.5 |

# Step 9 - What’s wrong here?

## (6 hr intervals)

| FT/CI | FT/CI | FT/CI | FT/CI |
|---|---|---|---|
| 1.0/1.0 | 6.0/6.0 | 6.0/6.0 | 5.5/5.5 |
| 2.5/2.5 | 5.0/6.0 | 5.5/6.0 | 5.0/5.5 |
| 3.5/3.5 | 4.5/6.0 | 4.5/5.5 | 5.0/5.5 |
| 5.0/5.0 | 4.0/5.0 | 4.5/5.5 | 5.0/5.5 |
| 6.5/6.5 | 3.5/4.5 | 4.5/5.5 | 5.0/5.5 |
| 7.0/7.0 | 2.5/4.0 | 4.0/5.0 | 5.0/5.5 |
| 7.5/7.5 | 2.0/3.5 | 3.5/4.5 | 5.0/5.5 |

**Development constraints all broken**

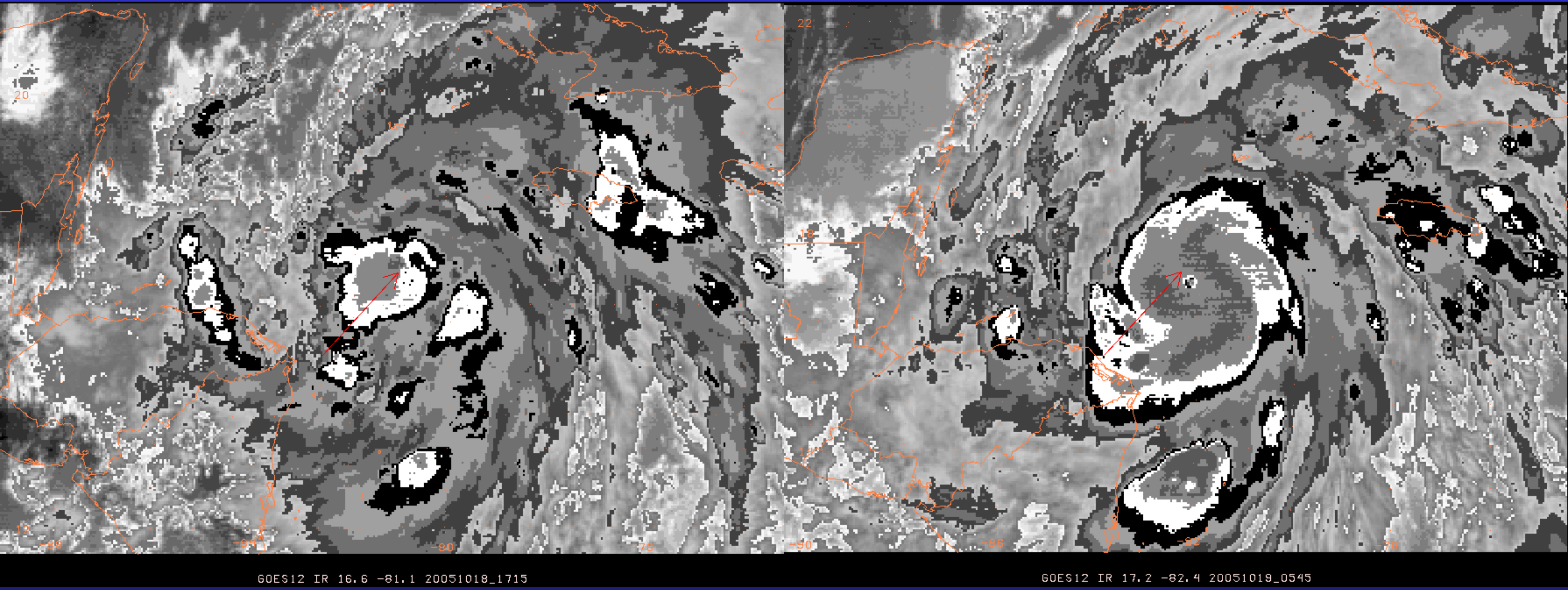
**CI > 1.0 above FT**

**CI needs to be held to highest FT during the past 12 hr**

# Why are there constraints?

- Weak systems sometimes lose all convection during the diurnal minimum
- Cloud patterns for weak systems sometimes look unrealistically strong
- Strong systems sometimes don’t intensify as quickly as the cloud pattern suggests
- In weakening systems, the decay of winds and pressures usually somewhat lags behind that of the cloud pattern
- Issue of constraints can be quite controversial

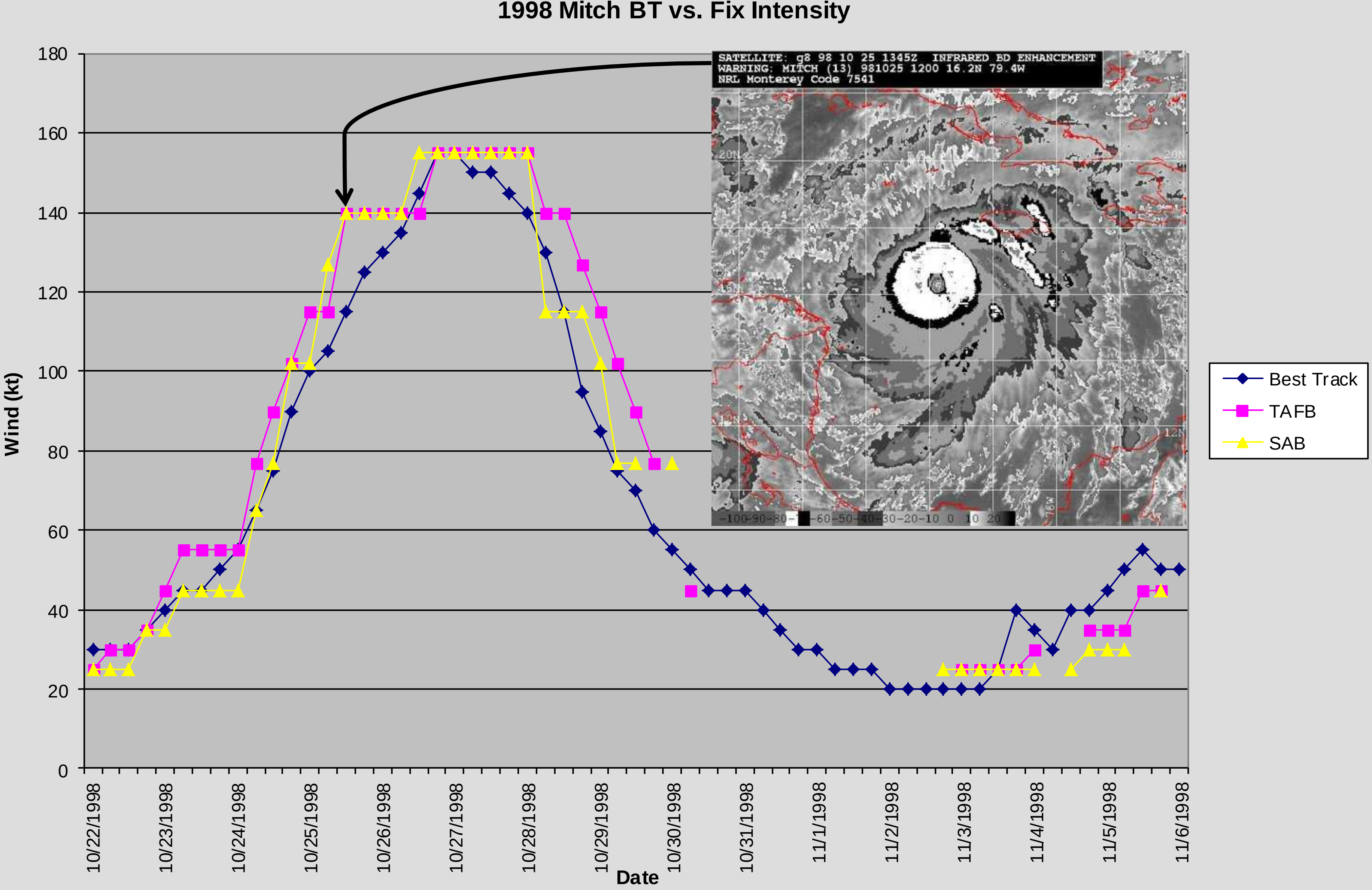
# Hurricane Wilma (2005)



**75 kt/975 mb** (Images ~12 hr apart) **150 kt/892 mb**

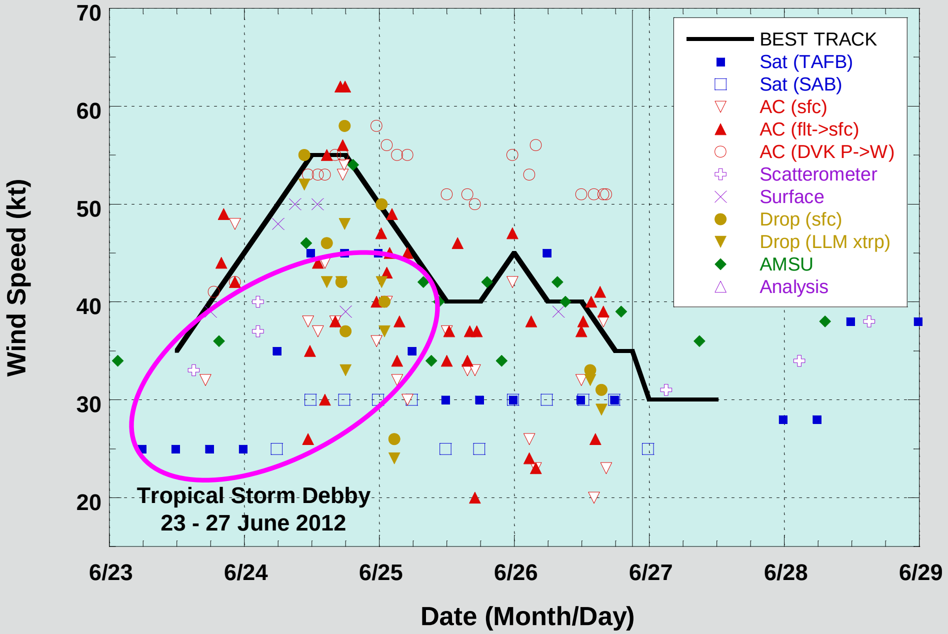
**Some tropical cyclones clearly violate the Dvorak development constraints. Wilma deepened from 970 mb to 882 mb in ~12 hr.**

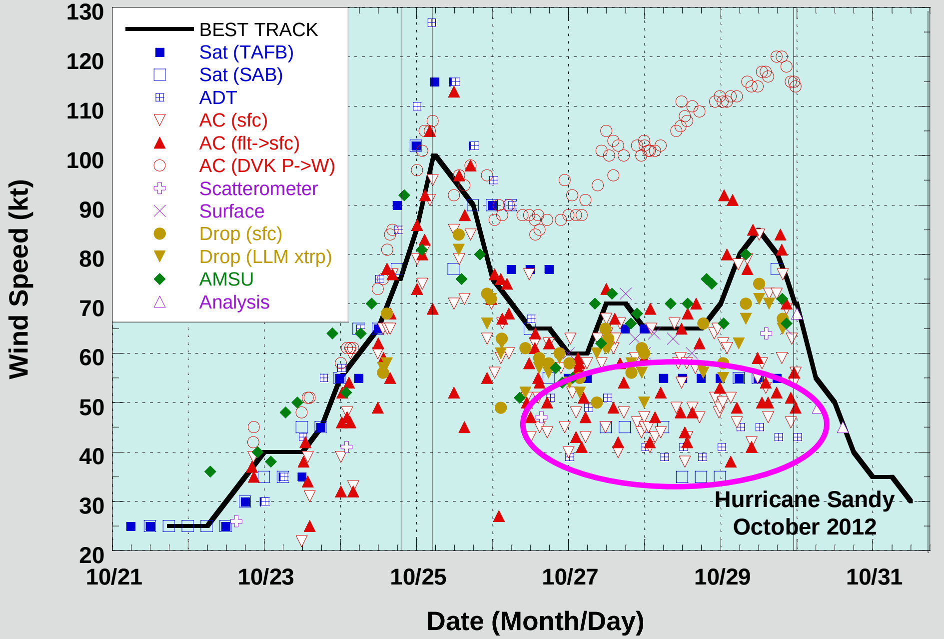
# Hurricane Mitch (1998)

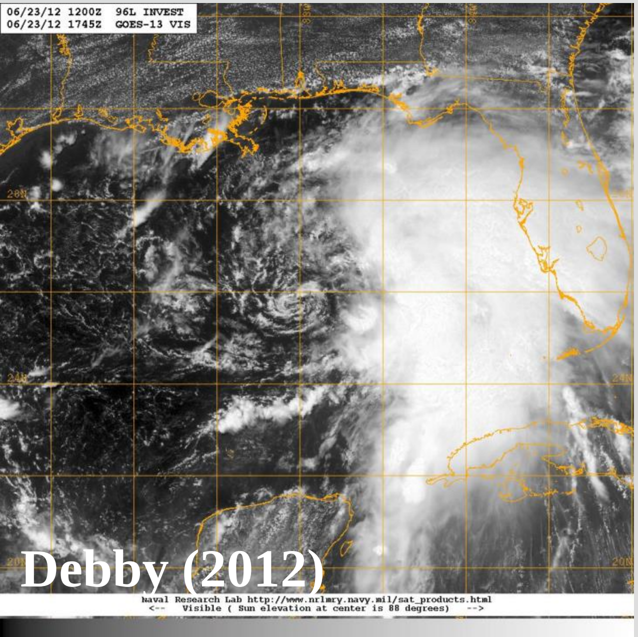


**Air recon intensity lagged behind Dvorak estimates during intensification.**

# Cyclones Stronger Than They Appeared

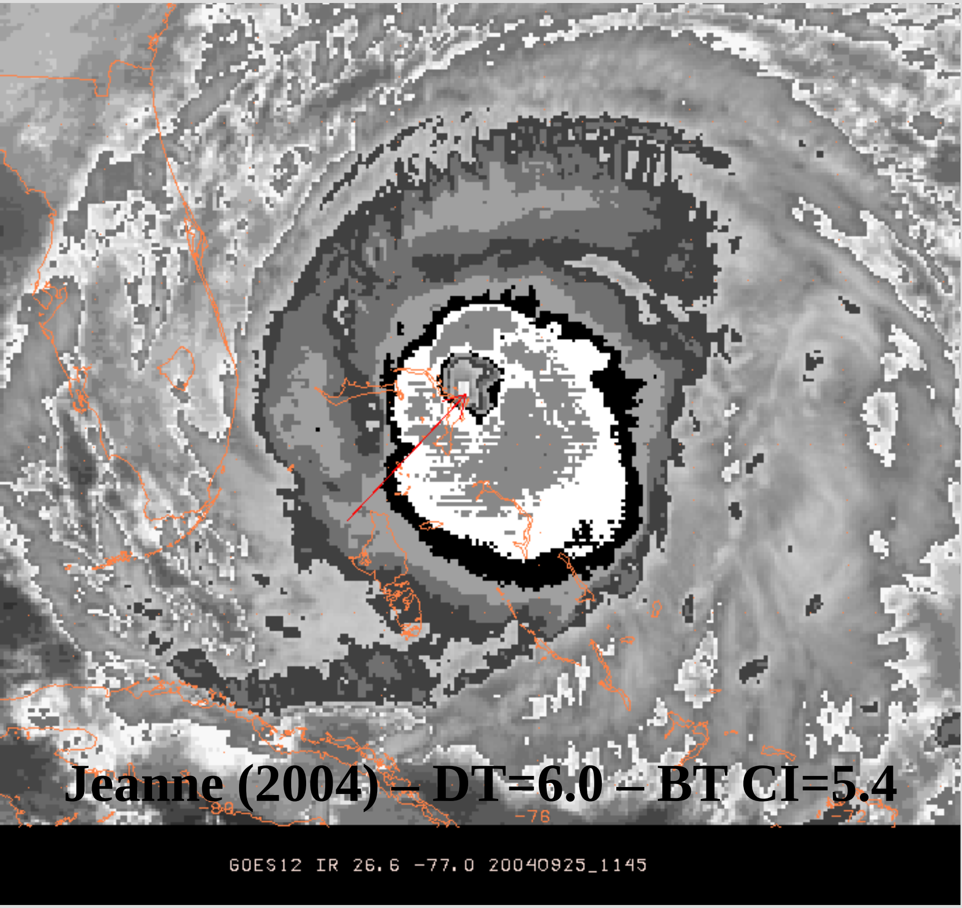




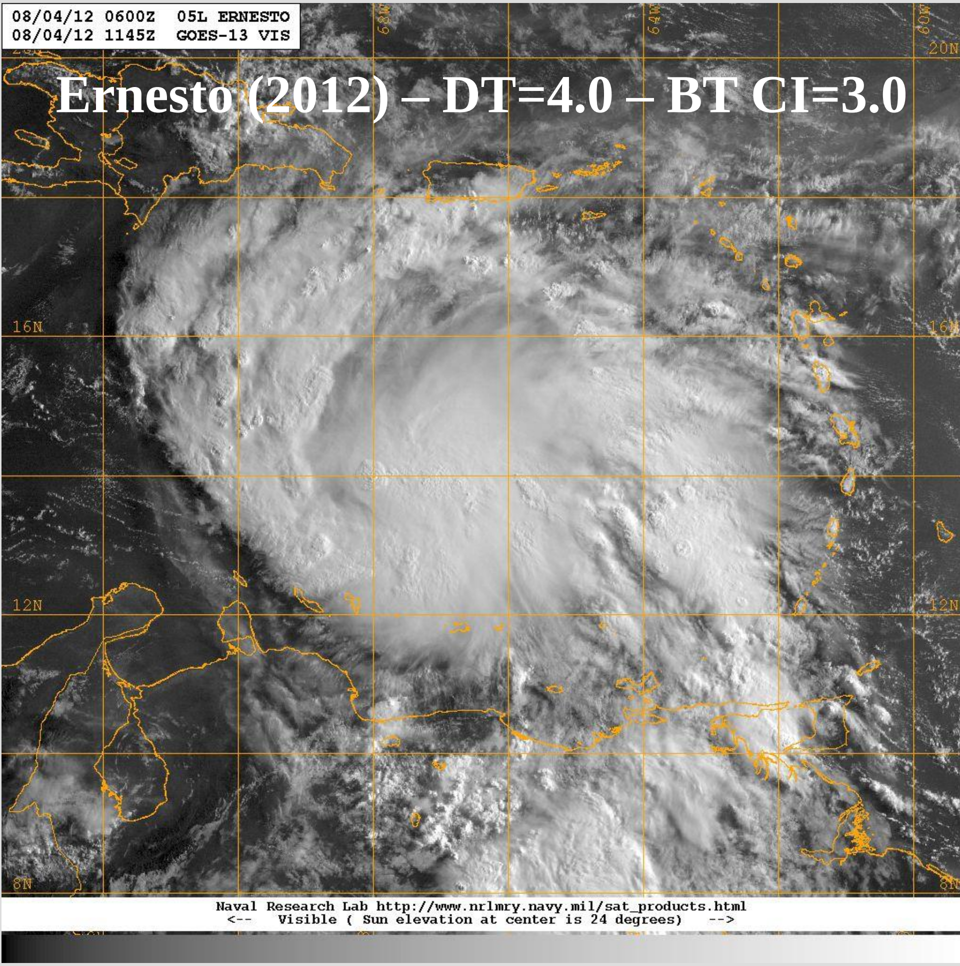


Reconnaissance data showed Debby and Sandy were stronger than their Dvorak intensity estimates. Dvorak estimates are less reliable for monsoonish cyclones (Debby) and partly baroclinic cyclones (Sandy).

# False Alarm Strong Appearances



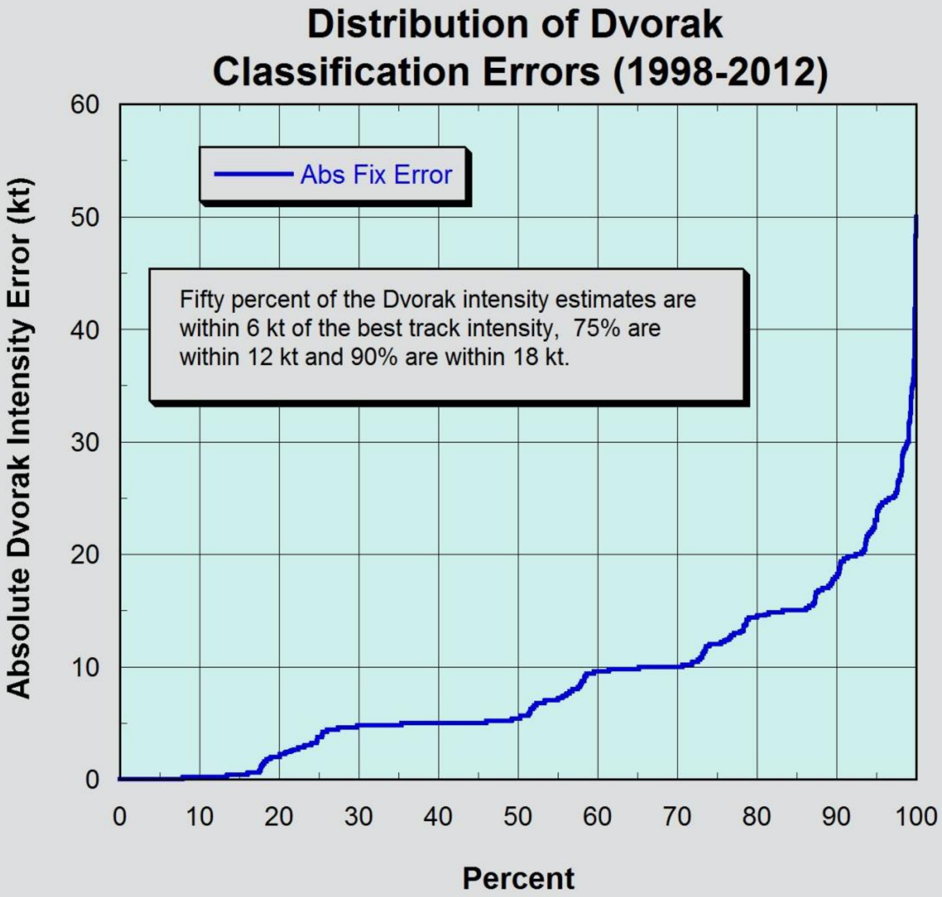
Jeanne (2004) – DT=6.0 – BT CI=5.4



Ernesto (2012) – DT=4.0 – BT CI=3.0

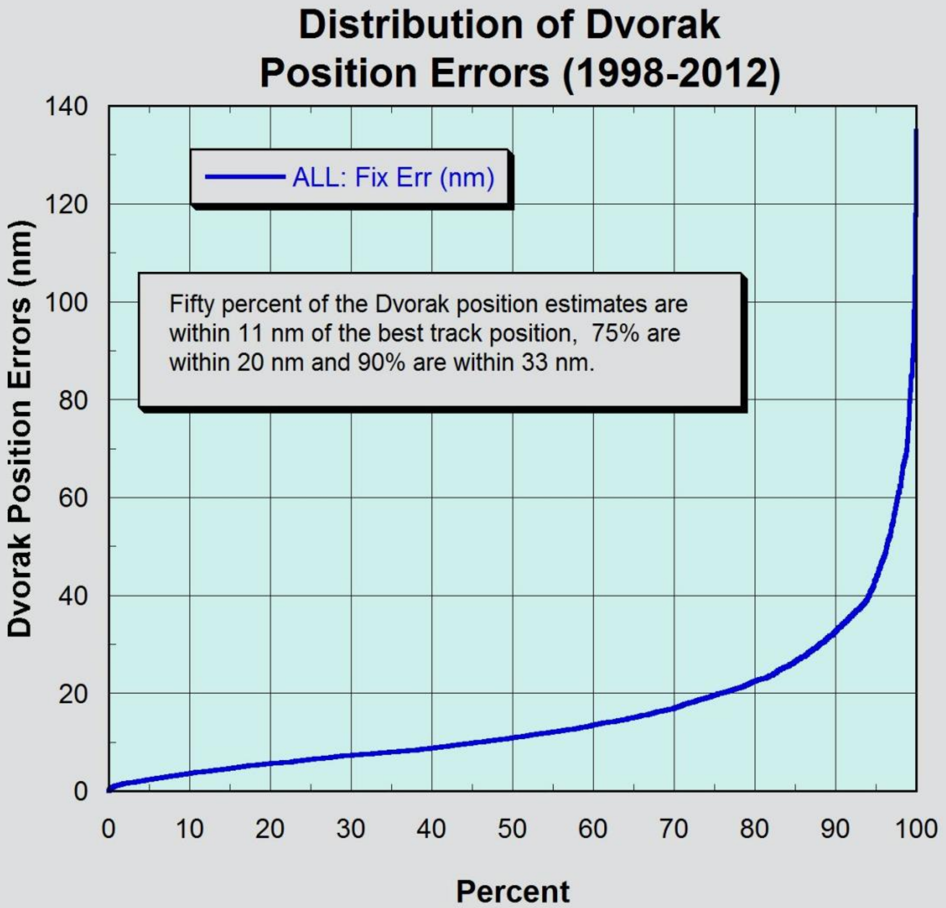
**Reconnaissance data showed Jeanne and Ernesto were not as strong as their satellite appearance. The cloud patterns weakened after these images.**

# Dvorak Error Distribution



Distribution of Dvorak Classification Errors (1998-2012)

Fifty percent of the Dvorak intensity estimates are within 6 kt of the best track intensity, 75% are within 12 kt and 90% are within 18 kt.



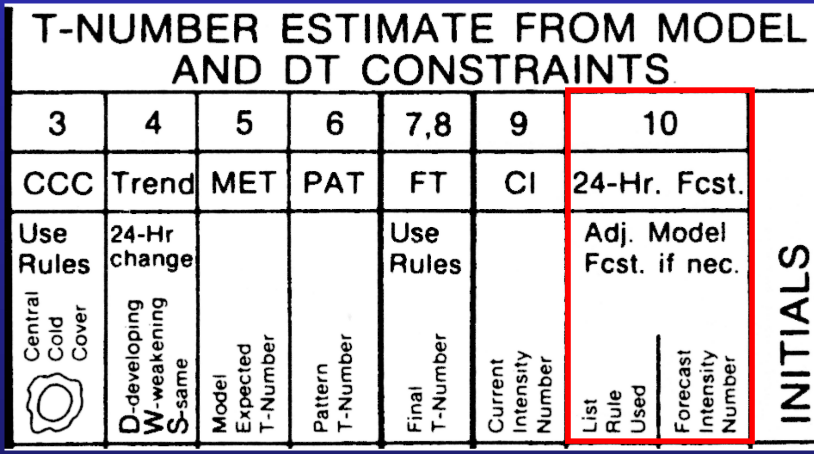
Distribution of Dvorak Position Errors (1998-2012)

Fifty percent of the Dvorak position estimates are within 11 nm of the best track position, 75% are within 20 nm and 90% are within 33 nm.

Images courtesy of Brown and Franklin

# Step 10 - Forecast Intensity (FI)

- This is a 24 hr forecast of the intensity based on the current CI and satellite-observed signals in the cyclone cloud pattern and the environment
- The set of rules has not been consistent through the revisions of the technique



T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | |
|---|---|---|---|---|---|---|---|---|
| CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | INITIALS |
| Central Cold Cover | D-developing<br>W-weakening<br>S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | List Rule Used | Forecast Intensity Number | |

# Step 10 - Forecast Intensity

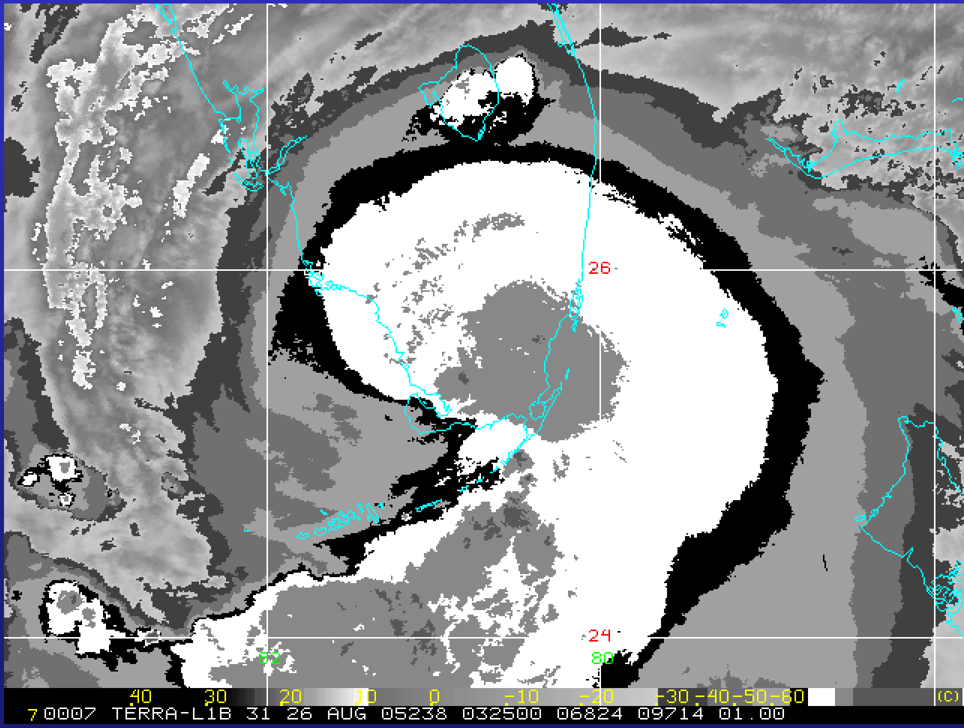
| Rule A - Strong Unfavorable Signs in Cloud Pattern: | Rule B - Strong Unfavorable Signs in Environment: |
|---|---|
| Persistent convective warming for > 12 hr | Cyclone about to move into stratocumulus clouds |
| CCC persisting for > 3 hr | Cyclone about to move onto land |
| Signs of shear or pattern elongation | Signs of shear |

Forecast: No development or half of the previous development rate

(Note: These two rules can work together.)

# Step 10 - Forecast Intensity Rule C - Strong Favorable Signs in Cloud Pattern

- Two successive observations of rapid development (24 hr change)
- One observation of rapid development and either a cold comma cloud pattern or multiple outflow channels
- Forecast: If FT ≤ 5.5, forecast rapid development (1.5 T-Numbers in 24 hr)



Katrina (2005) – cold comma cloud pattern

# Step 10 - Forecast Intensity

| Rule D - Weakened Cyclone Leaving Unfavorable Environment | Rule E - Cyclone Leaving Environment Where Development was Slowed | Rule F - Developing Cyclone Leaving Unfavorable Environment |
|---|---|---|
| Cyclone leaving conditions of Rule B | Cyclone leaving conditions of Rule B | Cyclone leaving conditions of Rule B |
| Forecast rapid development to prior maximum intensity, followed by normal development | Forecast previous rate of development | Forecast increase of 1 T-Number per day in rate of development (YIKES!) |

# Step 10 - Forecast Intensity
# Rule G - Cyclone Peaking

- Northward moving cyclones expected to peak 4 days after first T1
- Westward moving cyclones expected to peak 6 days after first T1
- All other cyclones expected to peak 5 days after first T1
- Forecast no change in intensity
- This rule is based mostly on climatology

# Step 10 - Forecast Intensity

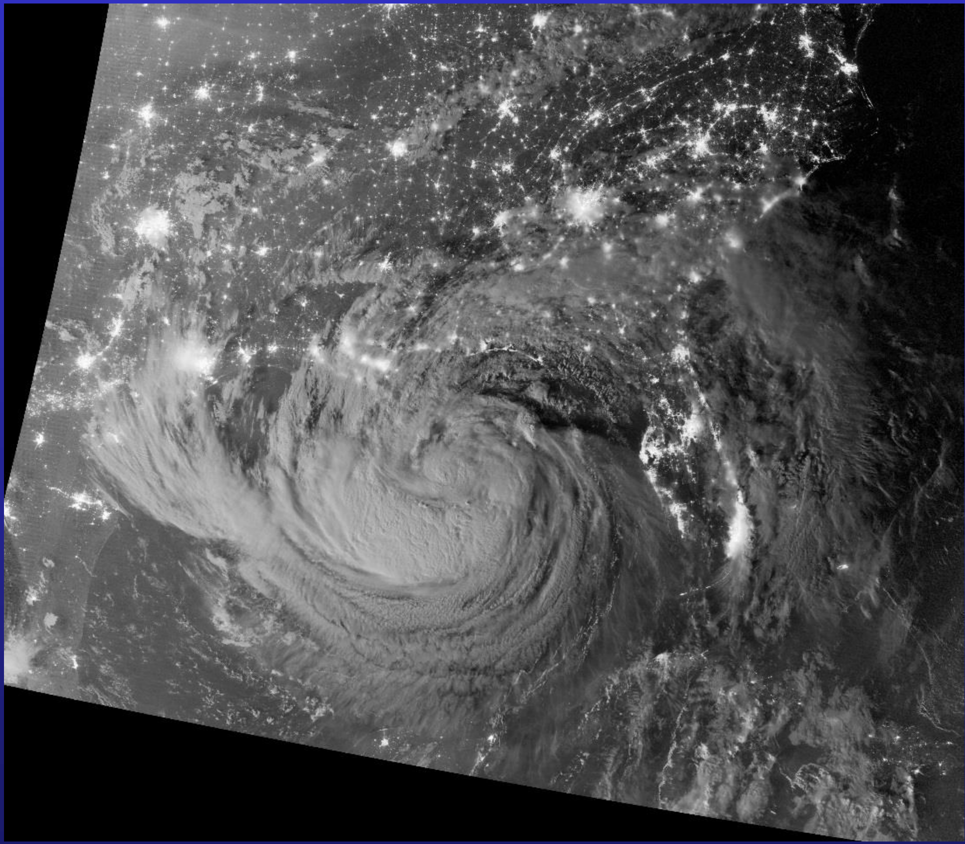
| Rule L - Large Eyes | Rule P - Persistence |
|---|---|
| For eyes 30 nm/56 km wide or larger with FT ≥ 6.0 | Use when no strong signals are present |
| Limit FI to 6.0 | Forecast trend from past 24 hr to continue |

# What to do for systems over land?

- Passage over land changes the TC energetics, as well as the relationship between the intensity and the cloud pattern.
- As a rule, don't classify systems over land. The Japanese Metrological Agency and the Joint Typhoon Warning Center classify systems over land, but the Tropical Prediction Center normally does not.
- There are subjective exceptions to the rule if the cyclone is close to the coast, over small islands, or over marsh land such as the Everglades or southern Louisiana. If a system is forming an eye while over land, it most likely should be classified.
- If the system moves back into the water and the classifications have been stopped, re-start classifications using the observed DT or PT

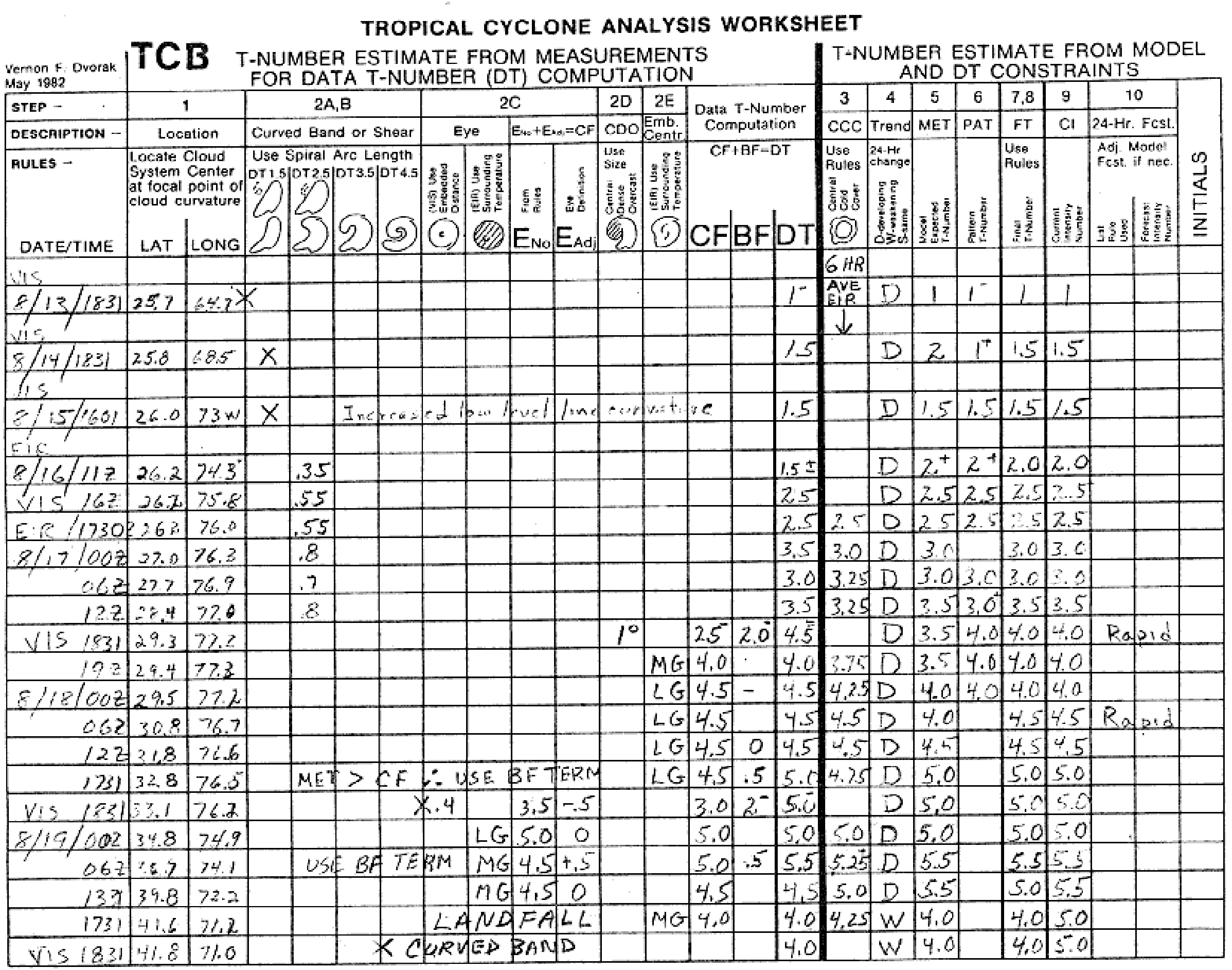
# A Few More Tips

- Previous daylight satellite imagery may help locate CSCs during night shifts
- If time permits, try multiple methods of classifying one system to see if the Data-T numbers agree (e.g. curved band and CDO or VIS and IR eyes) - if they don't, use the Data-T number closest to the MET
- Some imagers (DMSP/OLS, NPP/VIIRS, upcoming GOES-R/ABI) are sensitive enough to provide moonlight visible imagery, thus allowing use of VIS cloud patterns and center location at night



Isaac (2012) NPP Satellite Day-Night Moonlight Imagery

# Filling Out The Worksheet



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

**TCB**

T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

| STEP → | 1 | | 2A,B | | | | 2C | | | | 2D | 2E | Data T-Number Computation | | | 3 | 4 | 5 | 6 | 7,8 | 9 | 10 | | INITIALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESCRIPTION → | Location | | Curved Band or Shear | | | | Eye | | $E_{No}+E_{Adj}=CF$ | | CDO | Emb. Centr | | | | CCC | Trend | MET | PAT | FT | CI | 24-Hr. Fcst. | | |
| RULES → | Locate Cloud System Center at focal point of cloud curvature | | Use Spiral Arc Length | | | | | | | | Use Size | | CF+BF=DT | | | Use Rules | 24-Hr change | | | Use Rules | | Adj. Model Fcst. if nec. | | |
| DATE/TIME | LAT | LONG | DT1.5 | DT2.5 | DT3.5 | DT4.5 | (VIS) Use Embedded Distance | (EIR) Use Surrounding Temperature | $E_{No}$ From Rules | $E_{Adj}$ Eye Definition | Central Dense Overcast | (EIR) Use Surrounding Temperature | CF | BF | DT | Central Cold Cover | D-developing W-weakening S-same | Model Expected T-Number | Pattern T-Number | Final T-Number | Current Intensity Number | Last Rule Used | Forecast Intensity Number | |
| VIS | | | | | | | | | | | | | | | | 6 HR | | | | | | | | |
| 8/13/1831 | 25.7 | 64.7 | X | | | | | | | | | | | | 1- | AVE EIR | D | 1 | 1- | 1 | 1 | | | |
| VIS | | | | | | | | | | | | | | | | ↓ | | | | | | | | |
| 8/14/1831 | 25.8 | 68.5 | X | | | | | | | | | | | | 1.5 | | D | 2 | 1+ | 1.5 | 1.5 | | | |
| VIS | | | | | | | | | | | | | | | | | | | | | | | | |
| 8/15/1601 | 26.0 | 73W | X | | Increased low level line curvature | | | | | | | | | | 1.5 | | D | 1.5 | 1.5 | 1.5 | 1.5 | | | |
| EIR | | | | | | | | | | | | | | | | | | | | | | | | |
| 8/16/112 | 26.2 | 74.3 | | .35 | | | | | | | | | | | 1.5± | | D | 2.+ | 2+ | 2.0 | 2.0 | | | |
| VIS 162 | 26.2 | 75.8 | | .55 | | | | | | | | | | | 2.5 | | D | 2.5 | 2.5 | 2.5 | 2.5 | | | |
| EIR /1730 | 26.2 | 76.0 | | .55 | | | | | | | | | | | 2.5 | 2.5 | D | 2.5 | 2.5 | 3.5 | 2.5 | | | |
| 8/17/002 | 27.0 | 76.3 | | .8 | | | | | | | | | | | 3.5 | 3.0 | D | 3.0 | | 3.0 | 3.0 | | | |
| 062 | 27.7 | 76.9 | | .7 | | | | | | | | | | | 3.0 | 3.25 | D | 3.0 | 3.0 | 3.0 | 3.0 | | | |
| 122 | 28.4 | 77.0 | | .8 | | | | | | | | | | | 3.5 | 3.25 | D | 3.5 | 3.0+ | 3.5 | 3.5 | | | |
| VIS 1831 | 29.3 | 77.2 | | | | | | | | | 1° | | 2.5 | 2.0 | 4.5 | | D | 3.5 | 4.0 | 4.0 | 4.0 | Rapid | | |
| 192 | 29.4 | 77.3 | | | | | | | | | | MG | 4.0 | · | 4.0 | 3.75 | D | 3.5 | 4.0 | 4.0 | 4.0 | | | |
| 8/18/002 | 29.5 | 77.2 | | | | | | | | | | LG | 4.5 | – | 4.5 | 4.25 | D | 4.0 | 4.0 | 4.0 | 4.0 | | | |
| 062 | 30.8 | 76.7 | | | | | | | | | | LG | 4.5 | | 4.5 | 4.5 | D | 4.0 | | 4.5 | 4.5 | Rapid | | |
| 122 | 31.8 | 76.6 | | | | | | | | | | LG | 4.5 | 0 | 4.5 | 4.5 | D | 4.5 | | 4.5 | 4.5 | | | |
| 1731 | 32.8 | 76.5 | | MET > CF ∴ USE BF TERM | | | | | | | | LG | 4.5 | .5 | 5.0 | 4.75 | D | 5.0 | | 5.0 | 5.0 | | | |
| VIS 1831 | 33.1 | 76.2 | | | | | X.4 | | 3.5 | -.5 | | | 3.0 | 2- | 5.0 | | D | 5.0 | | 5.0 | 5.0 | | | |
| 8/19/002 | 34.8 | 74.9 | | | | | | LG | 5.0 | 0 | | | 5.0 | | 5.0 | 5.0 | D | 5.0 | | 5.0 | 5.0 | | | |
| 062 | 35.7 | 74.1 | | USE BF TERM | | | | MG | 4.5 | +.5 | | | 5.0 | .5 | 5.5 | 5.25 | D | 5.5 | | 5.5 | 5.5 | | | |
| 137 | 39.8 | 72.2 | | | | | | MG | 4.5 | 0 | | | 4.5 | | 4.5 | 5.0 | D | 5.5 | | 5.0 | 5.5 | | | |
| 1731 | 41.6 | 71.2 | | | | | LANDFALL | | | | | MG | 4.0 | | 4.0 | 4.25 | W | 4.0 | | 4.0 | 5.0 | | | |
| VIS 1831 | 41.8 | 71.0 | | | | X CURVED BAND | | | | | | | | | 4.0 | | W | 4.0 | | 4.0 | 5.0 | | | |

# Mistakes to Avoid

- **Adding BF numbers to a curved band DT!**
- **Placing too much emphasis on IR curved band, shear, and embedded center patterns over VIS curved band, shear, and CDO patterns**
- **Incorrect 24 hr trends and METs, most notably during the early stages of development**
- **Arbitrarily changing the development rate**
- **Improperly filled out worksheets and classification forms**
- **Not making copies of images**
- **Not using BD enhancement on IR images**

# Related Techniques

- Hebert-Poteat Subtropical Cyclones Technique
- Automated/Objective Dvorak Technique
- U. S. Military Miller-Lander XT Technique
- AMSU-based TC intensity estimates
- Satellite Consensus (SATCON) Technique
- Experimental Techniques - Microwave Data and Other Approaches

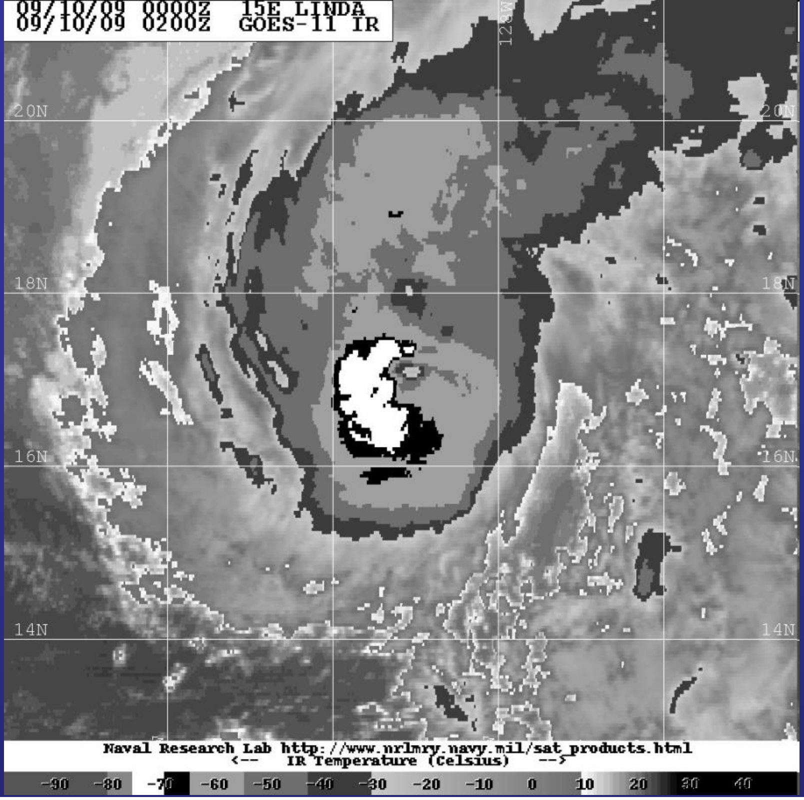
# Hebert-Poteat Subtropical Cyclone Technique

- Technique designed for subtropical cyclones, a ‘hybrid’ cyclone with characteristics of both tropical and extratropical cyclones
- It is designed as a complement to the Dvorak technique and to lead to the Dvorak technique when the cyclone acquires fully tropical characteristics
- Used operationally by satellite centers worldwide

# CIMSS Advanced Dvorak Technique (ADT)

- The latest in a series of objective versions of the Dvorak technique from CIMSS
- Can provide intensity estimates on <u>every</u> satellite image of a TC – some averaging is required!
- Includes Dvorak cloud patterns and some rules
- Latest version uses microwave data for improved intensity estimates of some cloud patterns.
- Automated center fixing and cloud pattern types occasionally need manual intervention.
- It is becoming operational at NESDIS/SAB, and will eventually be implemented at NHC.

http://cimss.ssec.wisc.edu/tropic2/misc/adt/info.html

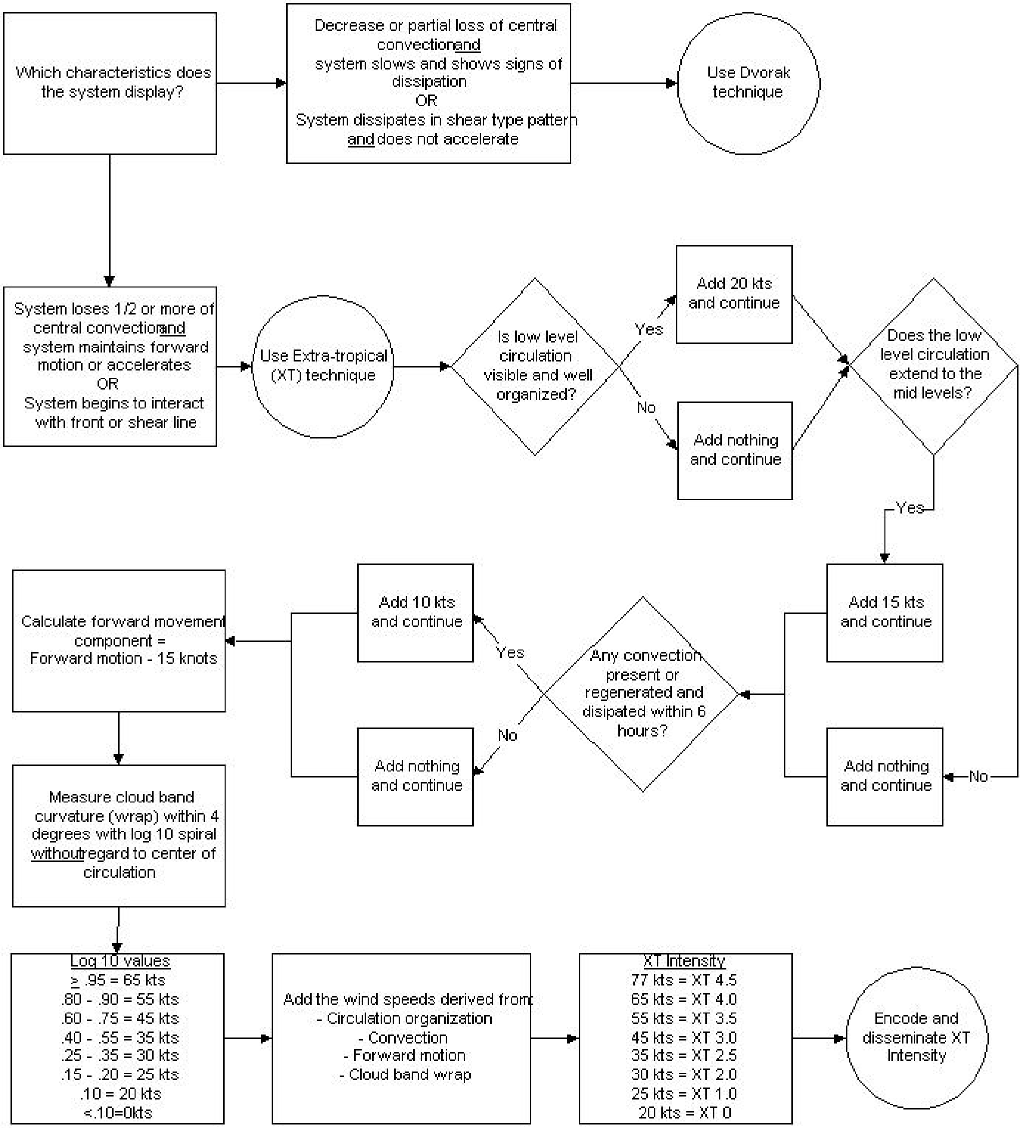


| Date/ Time | CI | Adj. Raw | Ini. Raw | Scene | Lat. | Lon. | Fix Method |
|---|---|---|---|---|---|---|---|
| 09/2330 | 3.9 | 4.0 | 4.0 | EMBC | 16.87 | 129.17 | FCST |
| 10/0000 | 3.9 | 4.0 | 4.0 | EMBC | 16.91 | 129.20 | FCST |
| 10/0030 | 3.9 | 3.9 | 3.9 | EMBC | 16.92 | 129.08 | SPRL |
| 10/0100 | 3.9 | 3.9 | 3.9 | UNIFRM | 16.86 | 129.11 | SPRL |
| 10/0130 | 4.0 | 4.4 | 5.5 | EYE | 17.02 | 129.14 | COMBO |
| 10/0200 | 4.0 | 3.7 | 3.7 | EMBC | 17.88 | 128.97 | SPRL |
| 10/0230 | 4.0 | 4.5 | 5.5 | EYE | 17.10 | 129.10 | SPRL |
| 10/0300 | 4.1 | 4.4 | 5.6 | EYE | 17.15 | 129.03 | SPRL |
| 10/0330 | 4.1 | 4.5 | 5.8 | EYE | 17.20 | 129.07 | SPRL |

# Miller-Lander XT Technique

- **Technique designed for tropical cyclones undergoing extratropical transition, when the Dvorak technique can produce unrealistically low intensities**
- **Like the Hebert-Poteat subtropical cyclone technique, it is a complement to the Dvorak technique**
- **Used operationally by the U. S. military tropical cyclone sites**

**http://home1.gte.net/anstett/XT_Pg00.htm**



Which characteristics does the system display?

Decrease or partial loss of central convection and system slows and shows signs of dissipation
OR
System dissipates in shear type pattern and does not accelerate

Use Dvorak technique

System loses 1/2 or more of central convection and system maintains forward motion or accelerates
OR
System begins to interact with front or shear line

Use Extra-tropical (XT) technique

Is low level circulation visible and well organized?

Yes

Add 20 kts and continue

No

Add nothing and continue

Does the low level circulation extend to the mid levels?

Yes

Add 15 kts and continue

No

Add nothing and continue

Any convection present or regenerated and disipated within 6 hours?

Yes

Add 10 kts and continue

No

Add nothing and continue

Calculate forward movement component =
Forward motion - 15 knots

Measure cloud band curvature (wrap) within 4 degrees with log 10 spiral without regard to center of circulation

Log 10 values
≥ .95 = 65 kts
.80 - .90 = 55 kts
.60 - .75 = 45 kts
.40 - .55 = 35 kts
.25 - .35 = 30 kts
.15 - .20 = 25 kts
.10 = 20 kts
<.10=0kts

Add the wind speeds derived from:
- Circulation organization
- Convection
- Forward motion
- Cloud band wrap

XT Intensity
77 kts = XT 4.5
65 kts = XT 4.0
55 kts = XT 3.5
45 kts = XT 3.0
35 kts = XT 2.5
30 kts = XT 2.0
25 kts = XT 1.0
20 kts = XT 0

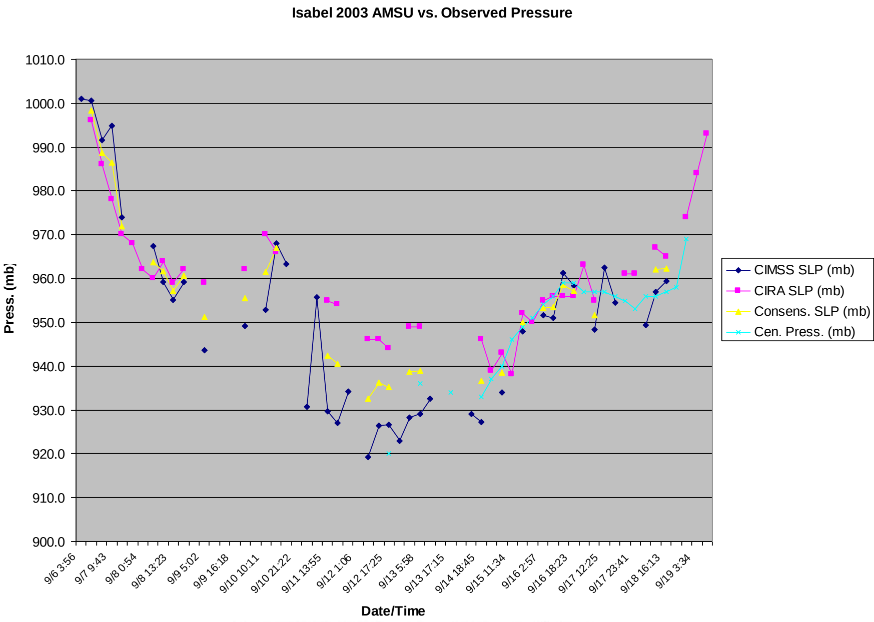
Encode and disseminate XT Intensity

**XT Technique Flowchart**

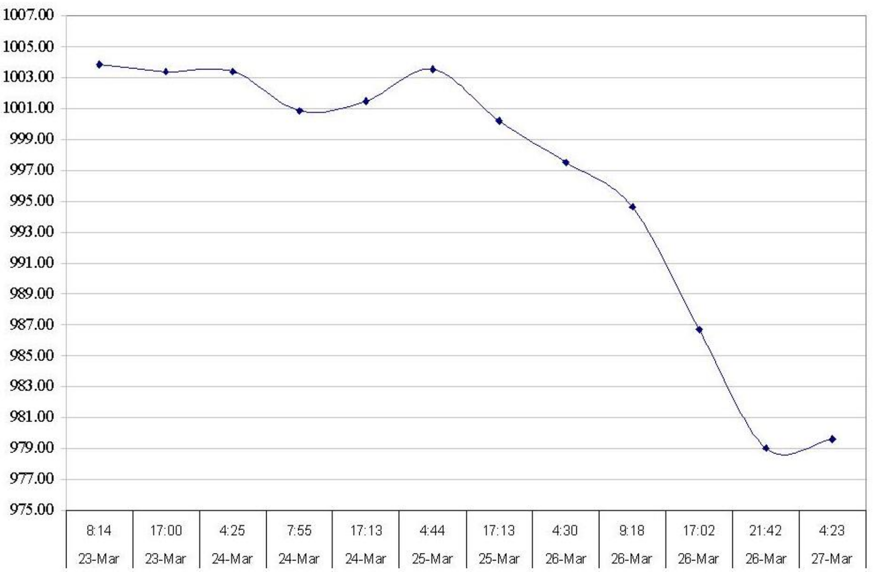
Note: Start in the upper left corner and determine the appropriate technique. If Dvorak, use NOAA/NESDIS 11. If XT, follow flowchart to intensity

# AMSU-Based Intensity Estimates

- AMSU - Advanced Microwave Sounding Unit on NOAA/METOP Polar Orbiters
- AMSU measures temperatures of the warm core at the top of a TC and derives the intensity from the core strength
- Sounder footprint is 50 km – problem with undersampling small TC cores
- AMSU estimates also suspect for subtropical systems, which have a different thermal structure
- NHC uses two AMSU algorithms – one from CIMSS and the other from CIRA
- Similar algorithms are being developed for SSM/IS and ATMS microwave sounder data


Isabel 2003 AMSU vs. Observed Pressure

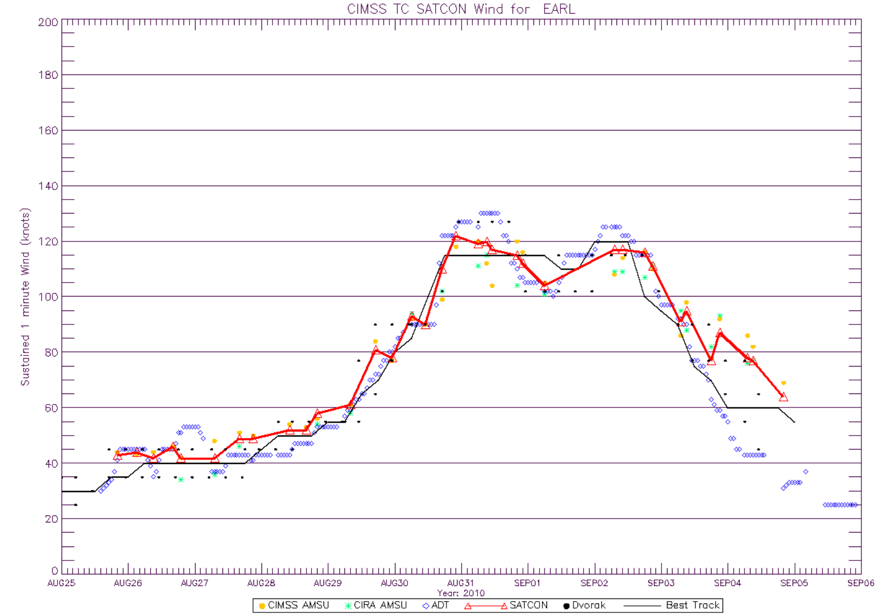
CIMSS AMSU for Brazil Tropical Cyclone

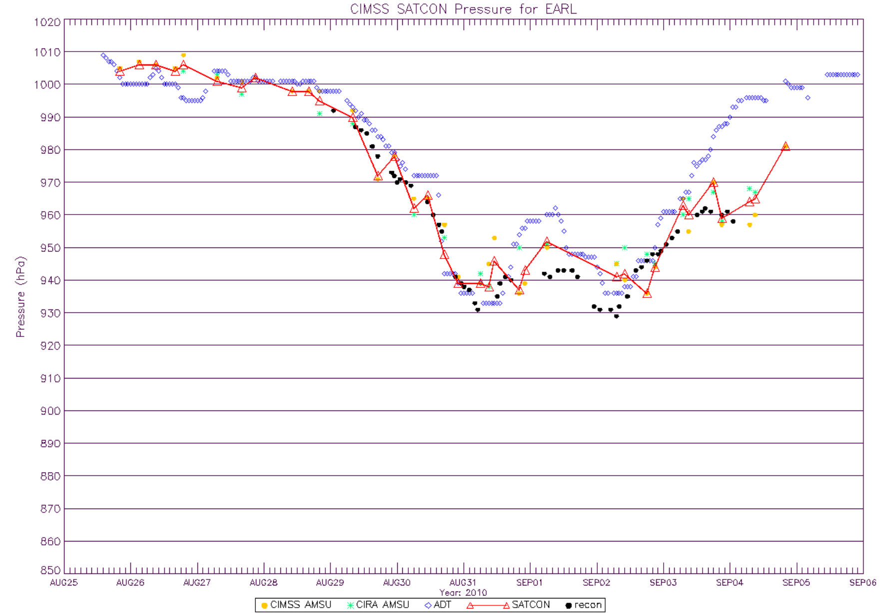


# CIMSS SATCON Technique

- **ADT and AMSU intensity estimates work well for certain ranges of TC intensity, structure, and satellite scanning geometry and less well for others**
- **Weighted averages of the estimates may produce a better result than any of the individual components. This is the basis of the CIMSS Satellite Consensus (SATCON) technique.**
- **SATCON is used experimentally at the NHC.**

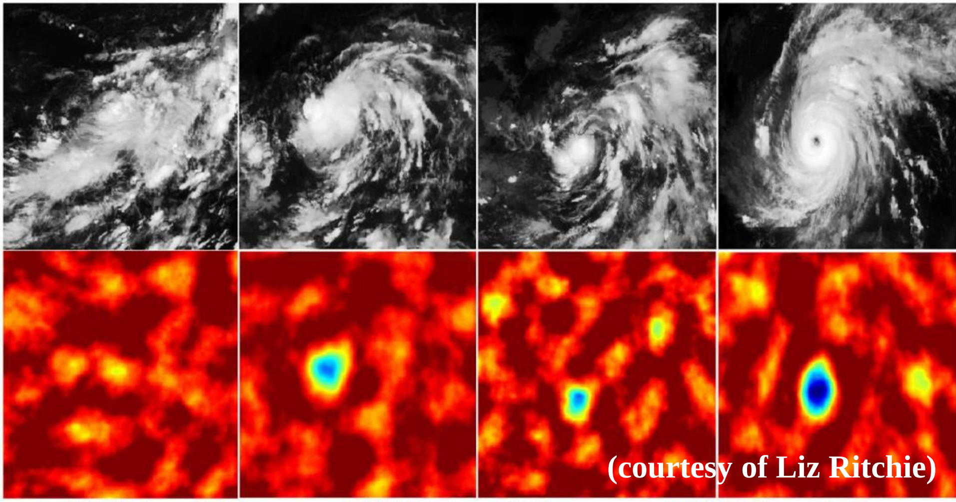
**http://cimss.ssec.wisc.edu/tropic2/real-time/satcon/**

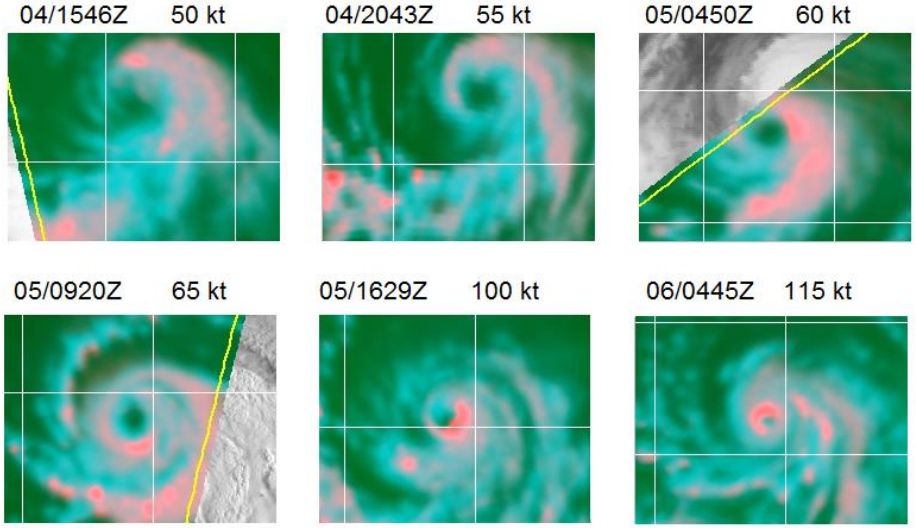




# Experimental techniques and other possible future developments

- Ritchie Deviation Angle Variance Technique
- Microwave-imagery-based equivalents of the Dvorak technique
- Dvorak-like techniques based on multispectral imagery (METEOSAT-Second Generation, GOES-R)


(courtesy of Liz Ritchie)



Precipitative ring feature formed about 04/20Z
24-hr intensity increase between 05/00Z and 06/00Z was 55 kt

(courtesy of Margie Kieper)

# Acknowledgements

- Vernon Dvorak – creator of the technique and of much of the material in these presentations
- Max Mayfield (former NHC director) – the previous teacher of the technique whose class material was the foundation for these presentations
- Ray Zehr (formerly of the Cooperative Institute For Research in the Atmosphere at Colorado State University) – several examples are from his Dvorak training module
- Andrew Burton (Australia Bureau of Meteorology) – whose comments helped improve the presentations
- Todd Kimberlain (NHC)  – collaborator in updating these presentations
- James Franklin and Dan Brown (NHC) – Dvorak Technique error slide
- The Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin – many satellite images and related technique material
- The Naval Research Laboratory, Monterey, CA – satellite images
- NASA – satellite images
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