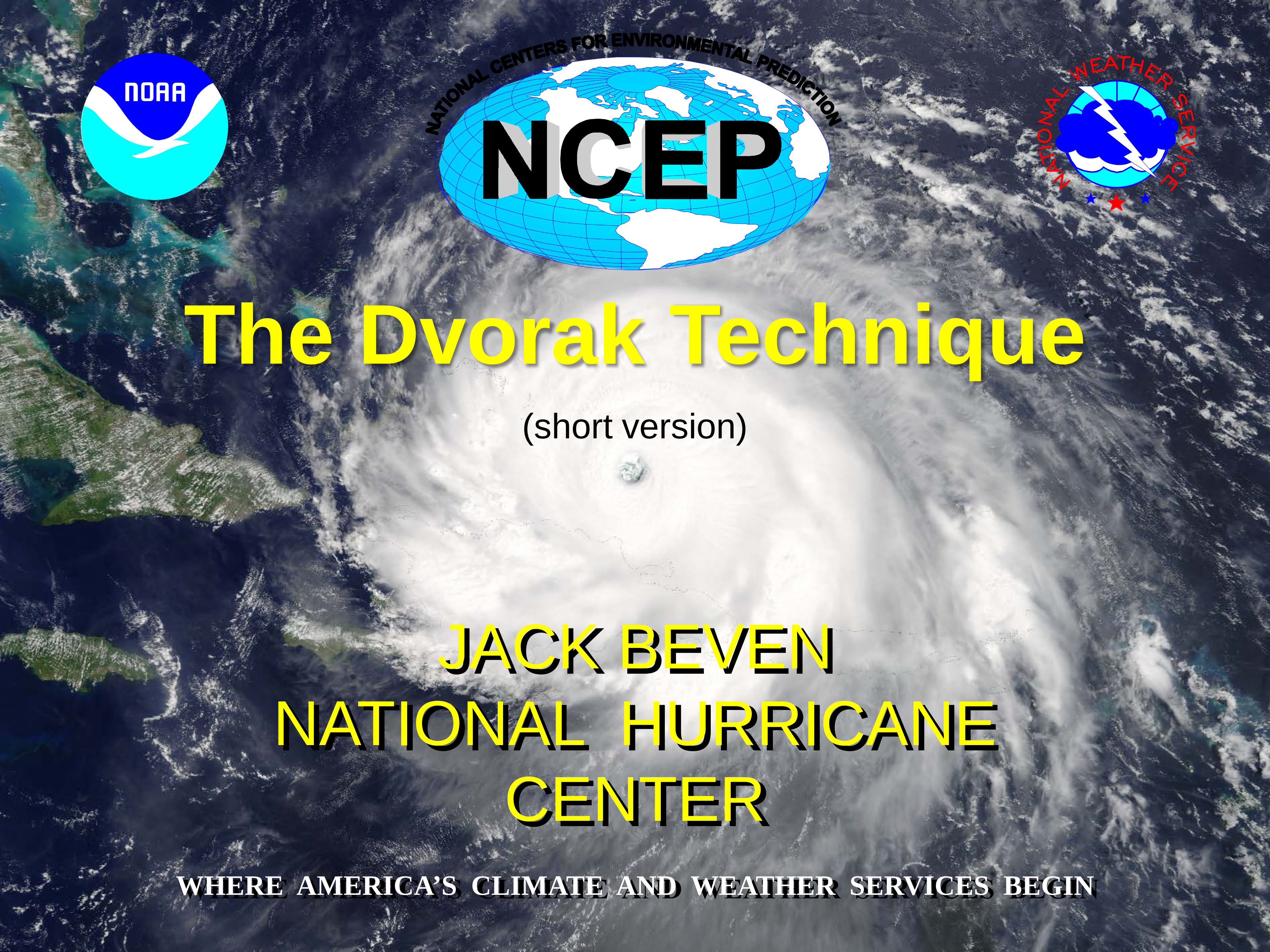


The Dvorak Technique

(short version)

JACK BEVEN
NATIONAL HURRICANE CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

What is the Dvorak Technique?

It is a statistical method for estimating the intensity of tropical cyclones (TCs) from *subjective* interpretation of satellite imagery.

It uses regular Infrared (IR) and Visible (VIS) imagery.

It employs a “measurement” of the TC convective cloud pattern and a set of rules.

It is used at TC warning centers around the world.

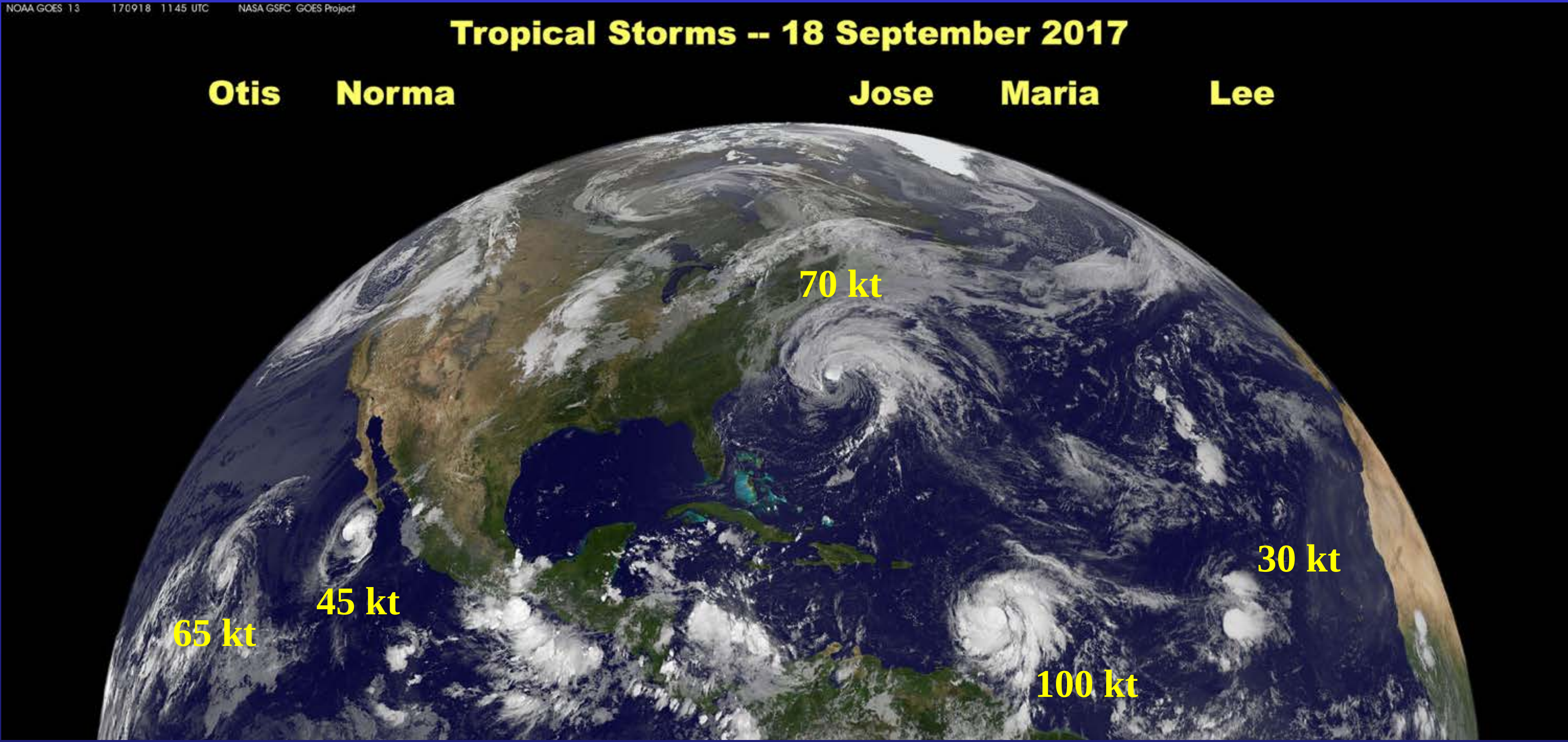
What the Dvorak Technique isn’t!

A direct measurement of wind, pressure, or any other meteorological variable associated with a TC!

A replacement for *in situ* measurements of a TC

Based rigorously on the physical principles of the atmosphere

Dvorak Technique Premise

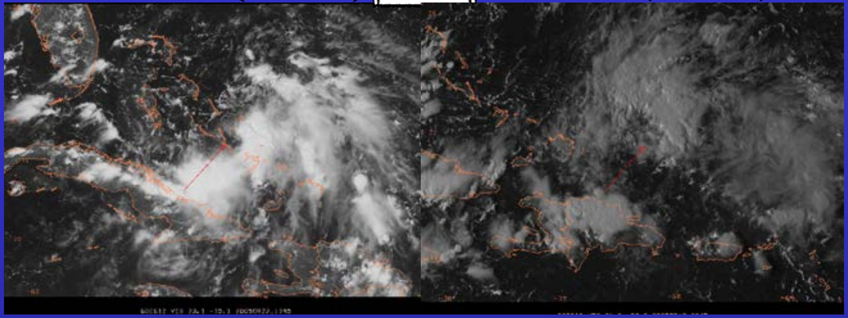


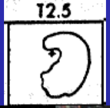
There is a (imperfect) correlation between the intensity of a TC and its satellite observed cloud pattern during both development and decay.

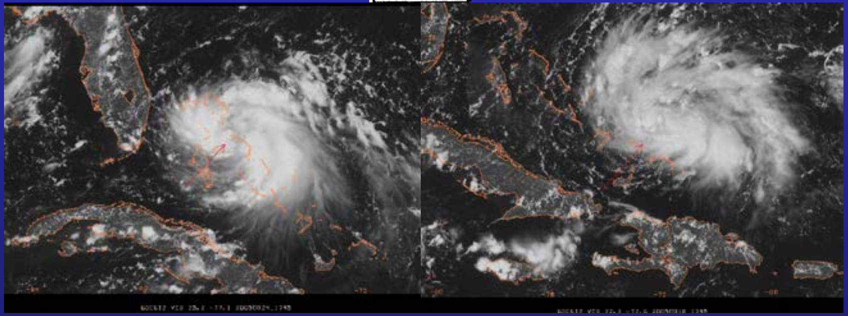
TC Cloud Patterns – Developing

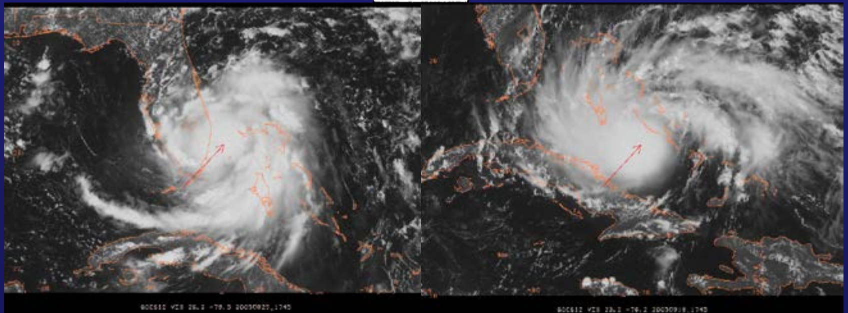
Katrina (2005)

Rita (2005)



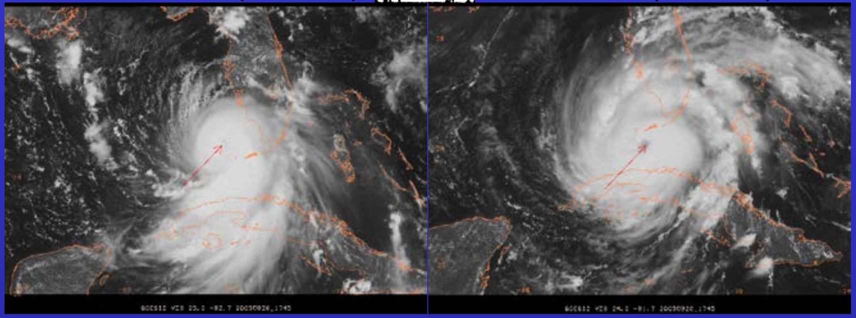


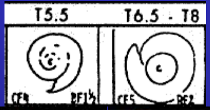


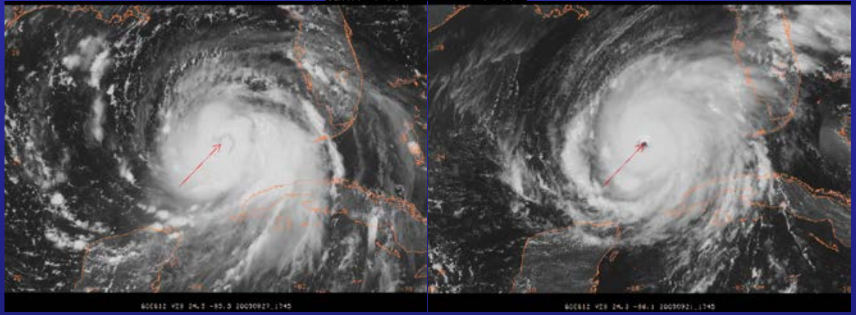


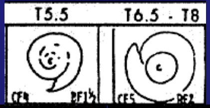
Katrina (2005)

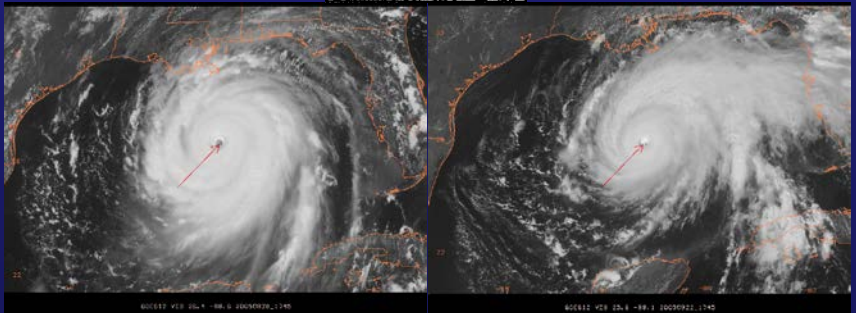
Rita (2005)





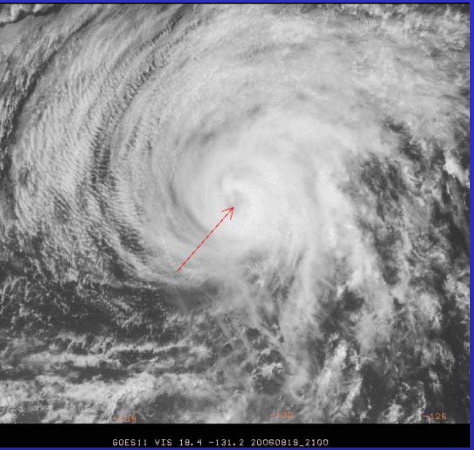




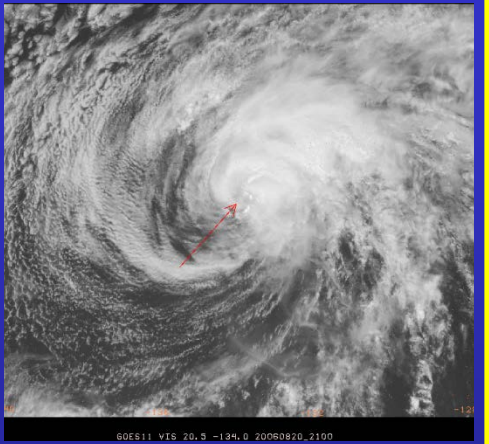


TC Cloud Patterns - Weakening

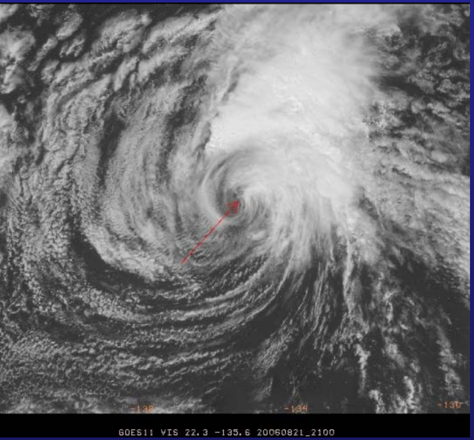
Hector 2006



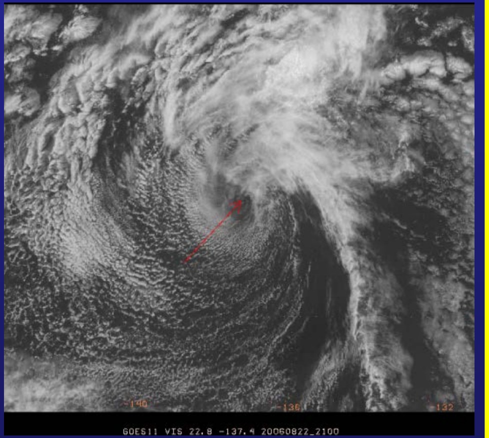
19 Aug. 2100 UTC



20 Aug. 2100 UTC

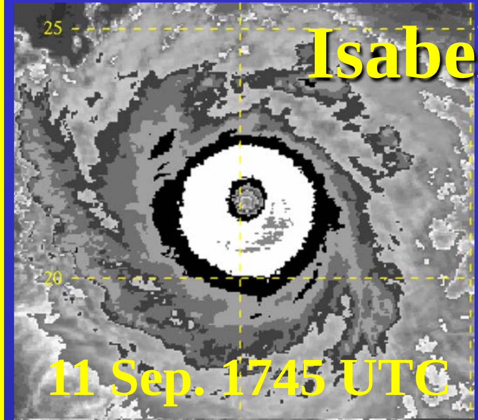


21 Aug. 2100 UTC

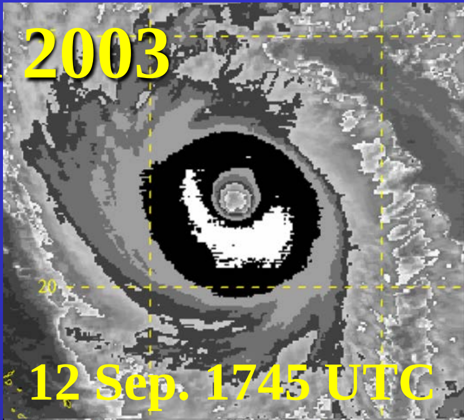


22 Aug. 2100 UTC

Isabel 2003



11 Sep. 1745 UTC



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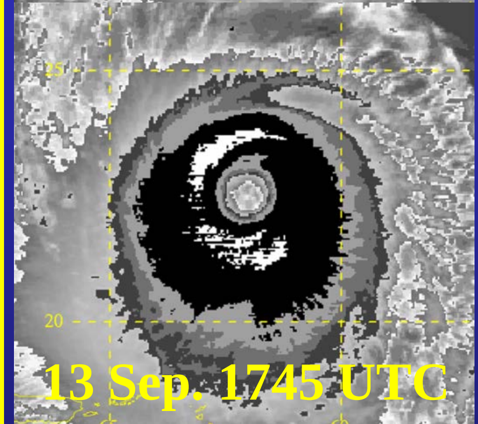

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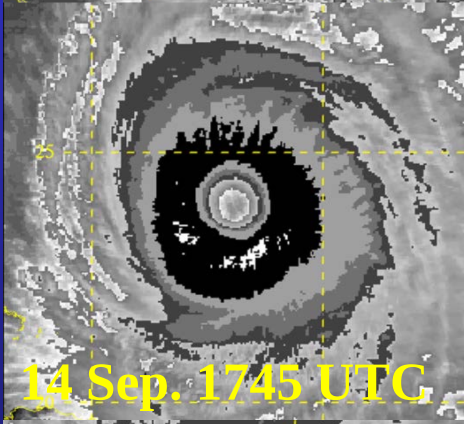
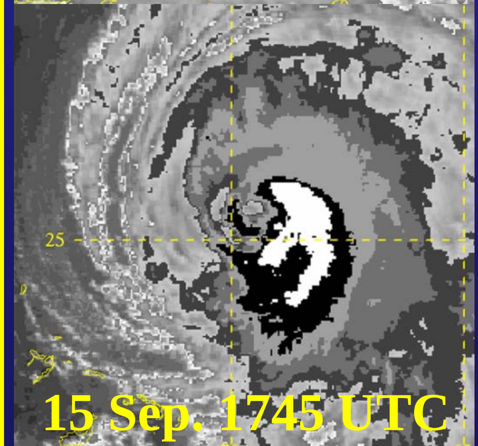
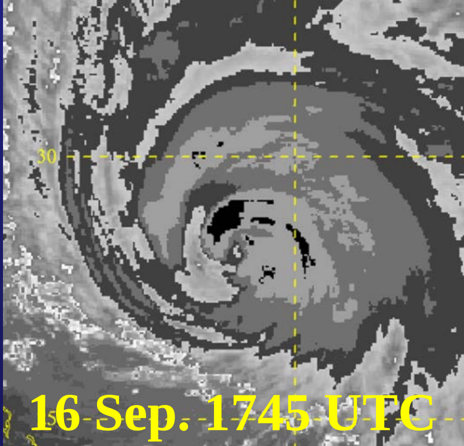


14 Sep. 1745 UTC

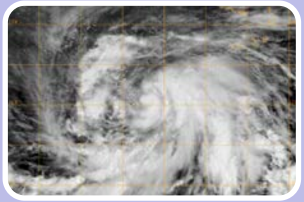


15 Sep. 1745 UTC

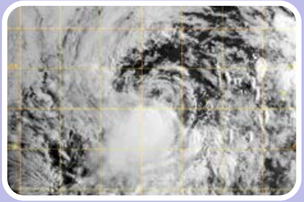


16 Sep. 1745 UTC

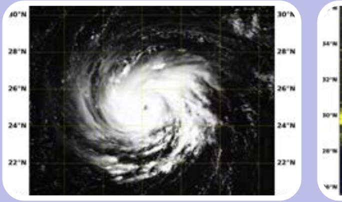
Dvorak Technique Cloud Patterns



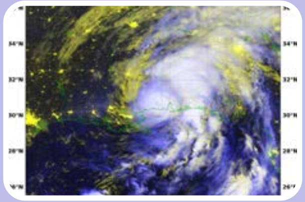
Curved Band (VIS and IR)



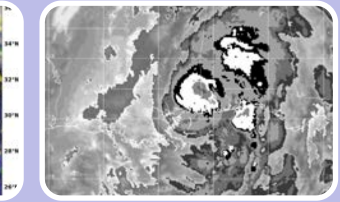
Shear (VIS and IR)



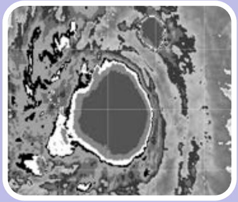
Eye (VIS and IR)



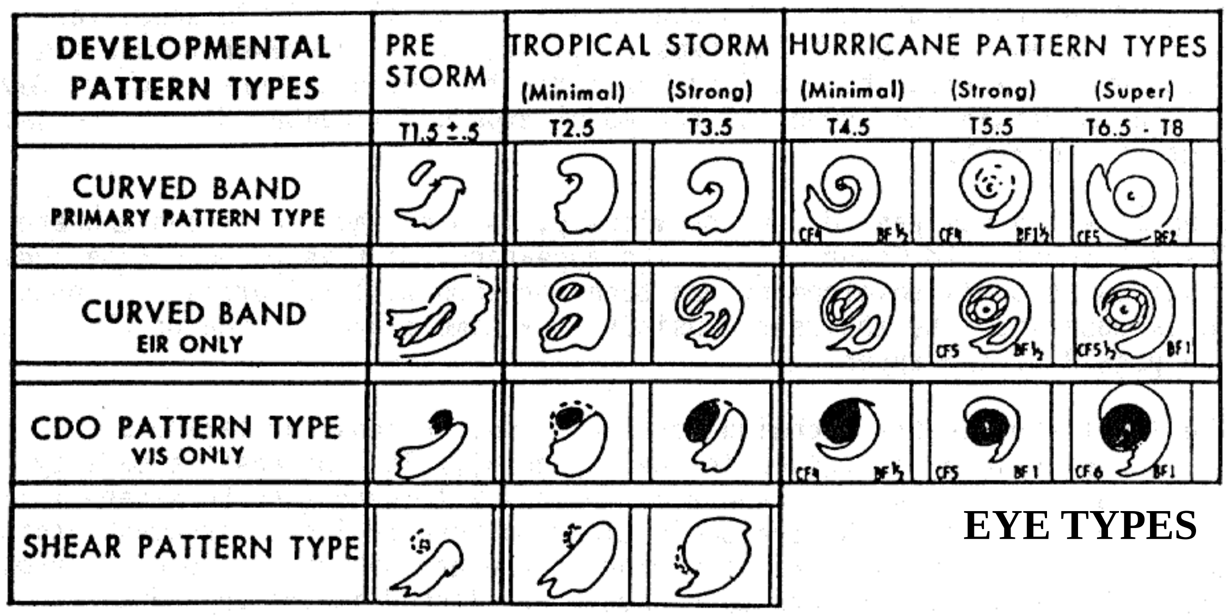
Central Dense Overcast (VIS)



Embedded Center (IR)

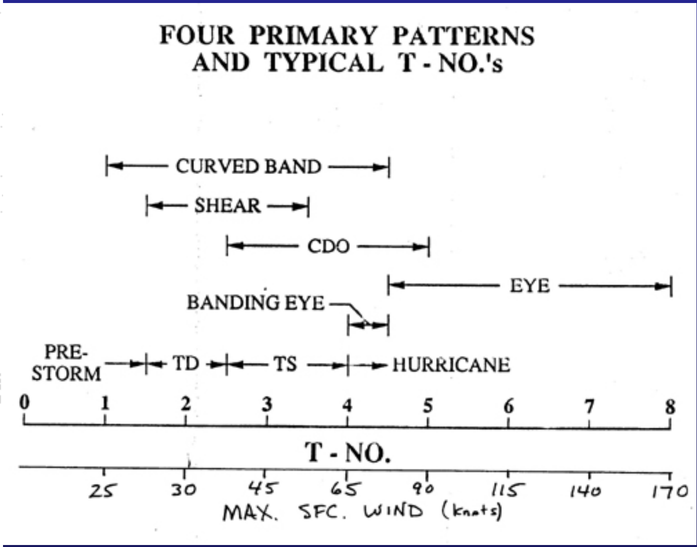


Central Cold Cover (VIS and IR)



DEVELOPMENTAL PATTERN TYPES	PRE STORM	TROPICAL STORM (Minimal)	(Strong)	HURRICANE PATTERN TYPES (Minimal)	(Strong)	(Super)
	T1.5 ± .5	T2.5	T3.5	T4.5	T5.5	T6.5 - T8
CURVED BAND PRIMARY PATTERN TYPE				CF4 BF½	CF4 BF1½	CF5 BF2
CURVED BAND EIR ONLY					CF5 BF½	CF5½ BF1
CDO PATTERN TYPE VIS ONLY				CF4 BF½	CF5 BF1	CF6 BF1
SHEAR PATTERN TYPE						

EYE TYPES



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

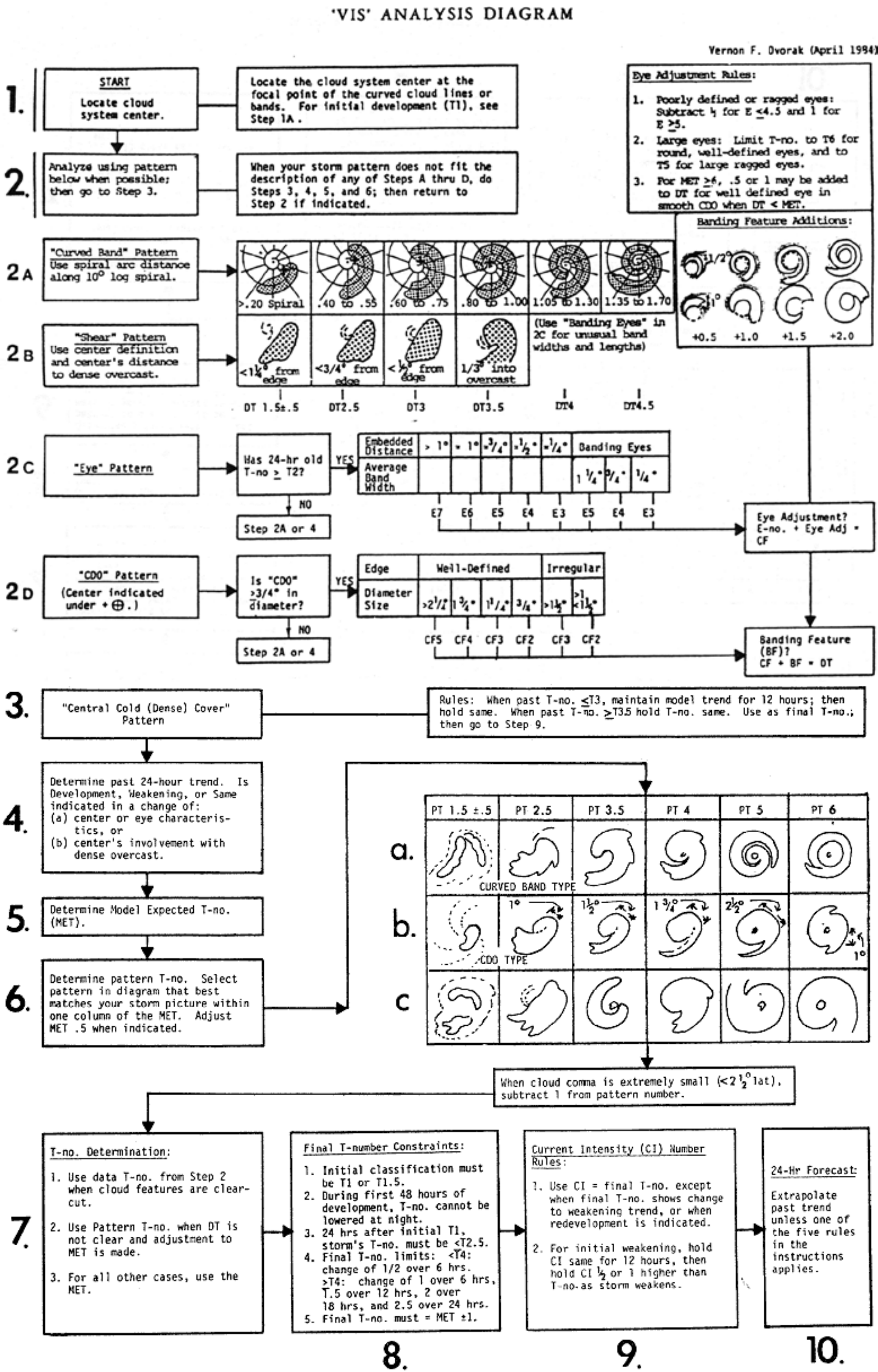
	1-minute MSW				NHC/CPHC/JTWC	
CI Number	(kt)	(mph)	(km/ h)	(m/s)	MSLP (ATL/EPAC)	MSLP (NW Pacific)
1.0	25	29	46	13		
1.5	25	29	46	13		
2.0	30	35	56	15	1009 mb	1000 mb
2.5	35	40	65	18	1005 mb	997 mb
3.0	45	52	83	23	1000 mb	991 mb
3.5	55	63	102	28	994 mb	984 mb
4.0	65	75	120	33	987 mb	976 mb
4.5	77	89	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)
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)



'VIS' ANALYSIS DIAGRAM

Vernon F. Dvorak (April 1994)

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.

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.

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

2D "CDO" Pattern (Center indicated under + ⊕.)

3. "Central Cold (Dense) Cover" Pattern

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

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

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

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

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

7. T-no. Determination:

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

8. Final T-number Constraints:

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

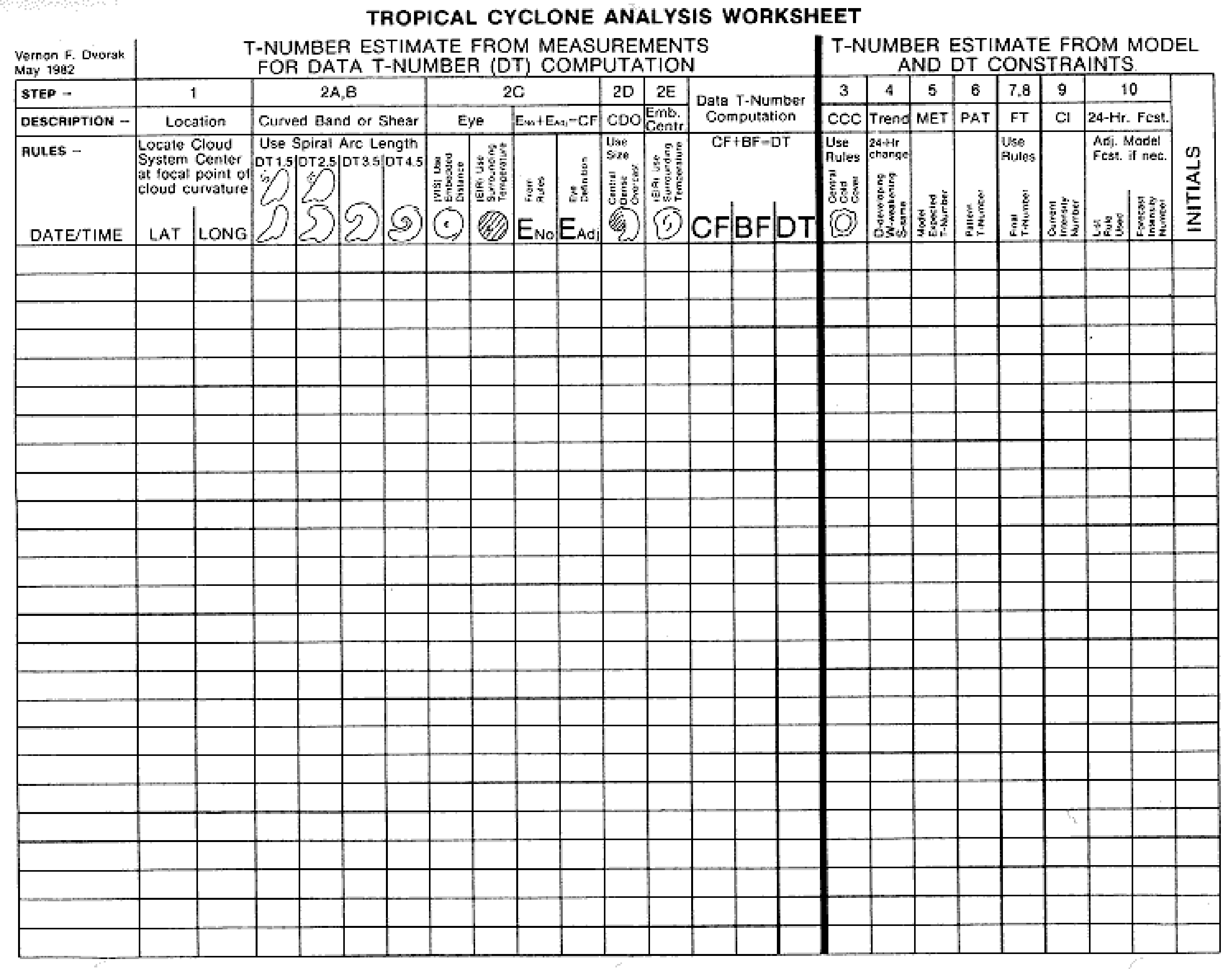
9. Current Intensity (CI) Number Rules:

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

10. 24-Hr Forecast:

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

Dvorak Technique Worksheet



TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
May 1982

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

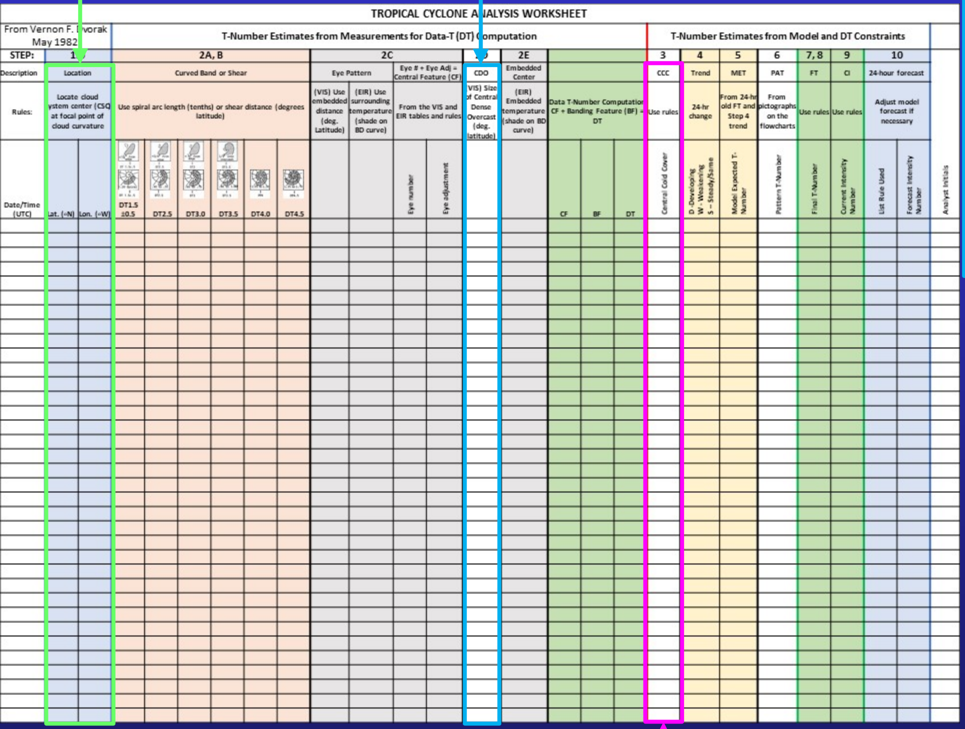
T-NUMBER ESTIMATE FROM MODEL AND DT CONSTRAINTS

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 DT1.5	DT2.5	DT3.5	DT4.5	(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 change D-developing W-weakening S-same	Model Expected T-Number	Pattern T-Number	Use Rules Final T-Number	Current Intensity Number	Adj. Model Fcst. if nec. Last Rule Used	Forecast Intensity Number	
DATE/TIME	LAT	LONG							E_{No}	E_{Adj}			CF	BF	DT									

TROPICAL CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation															T-Number Estimates from Model and DT Constraints								
STEP:	1.0		2A, B						2C				2D	2E				3	4	5	6	7, 8	9	10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	 DT1.5 ±0.5	 DT2.5	 DT3.0	 DT3.5	 DT4.0	 DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

Dvorak Technique Terms



TROPICAL CYCLONE ANALYSIS WORKSHEET

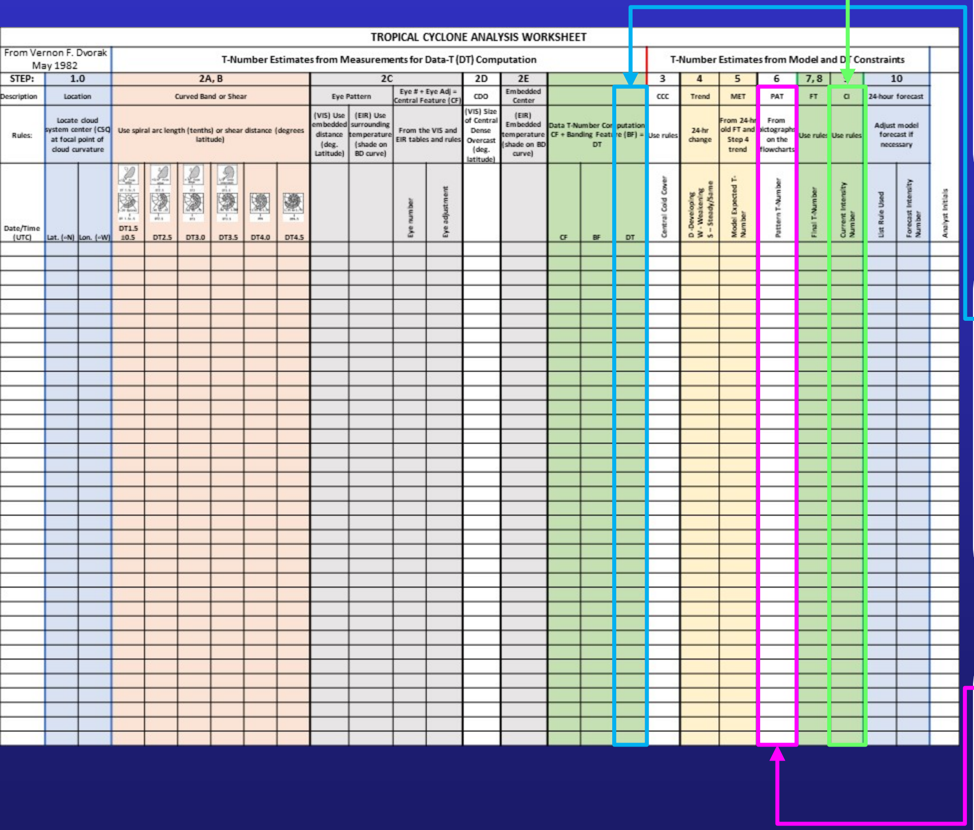
From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																	T-Number Estimates from Model and DT Constraints								
STEP:	1		2A, B						2C				[illegible]	2E				3	4	5	6	7, 8	9	10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D - Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

CSC - Cloud System Center - 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 - Central Dense Overcast - A dense solid-looking mass of clouds covering the CSC, often lying within the curve of the cyclone's curved cloud band.

CCC - Central Cold Cover - A large cold or dense overcast covering the CSC that lacks structure and obscures the cyclone center.

Dvorak Technique Terms



TROPICAL CYCLONE ANALYSIS WORKSHEET

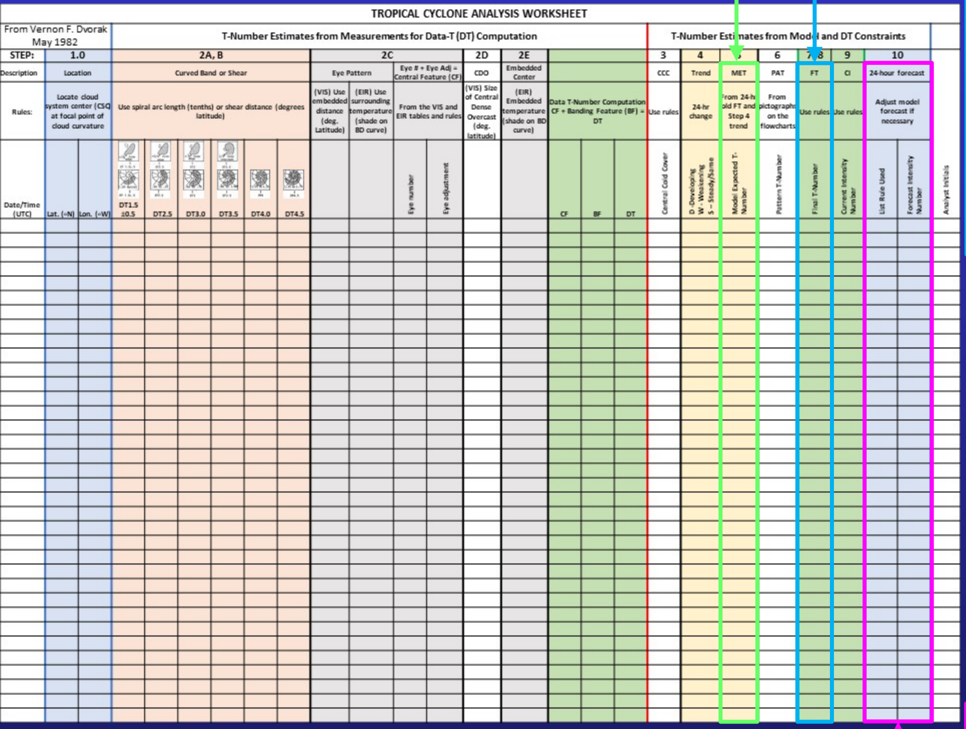
From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation															T-Number Estimates from Model and DT Constraints								
STEP:	1.0		2A, B						2C				2D	2E				3	4	5	6	7, 8		10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

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

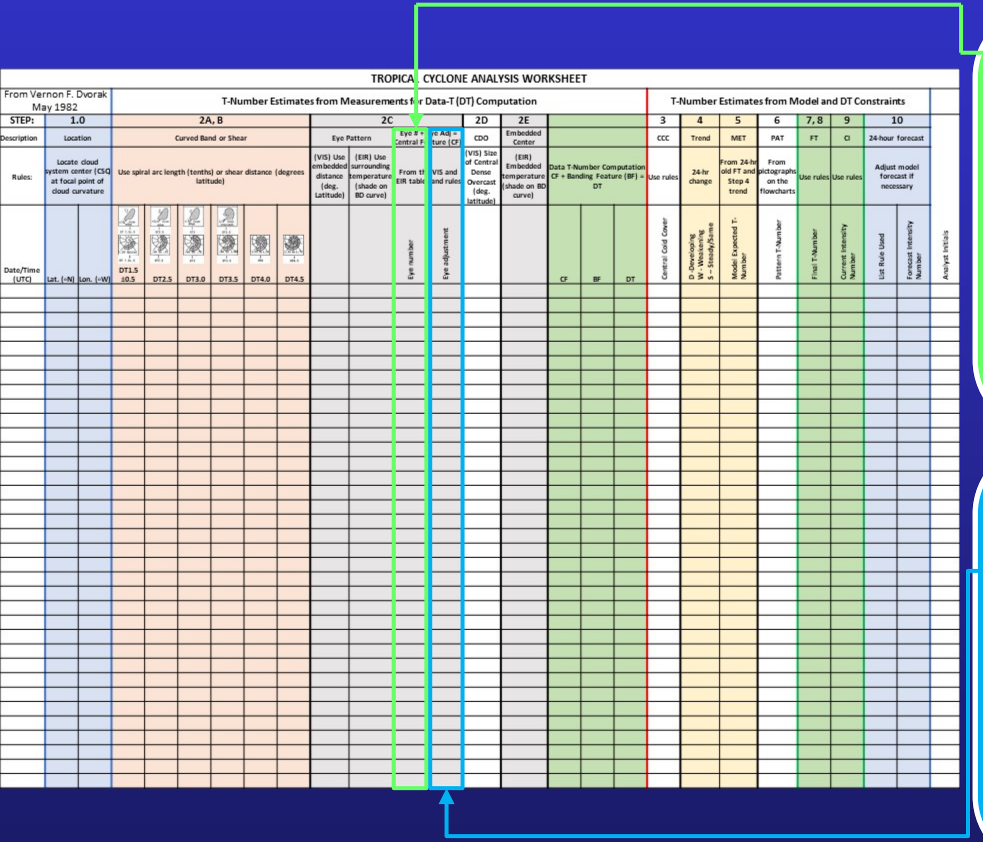
From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																	T-Number Estimates from Model and DT Constraints								
STEP:	1.0		2A, B						2C				2D	2E				3	4		6	7 8	9	10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D - Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

MET Number **- <u>M</u>odel <u>E</u>xpected-<u>T</u> number - The intensity estimate from the 24-h old FT number and a determined intensity trend.**

FT Number **- <u>F</u>inal-<u>T</u> 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 h later.**

FI Number **- <u>F</u>orecast <u>I</u>ntensity number - 24 h intensity forecast based on the CI and observed signals in the cyclone cloud pattern and the environment.**

Dvorak Technique Terms



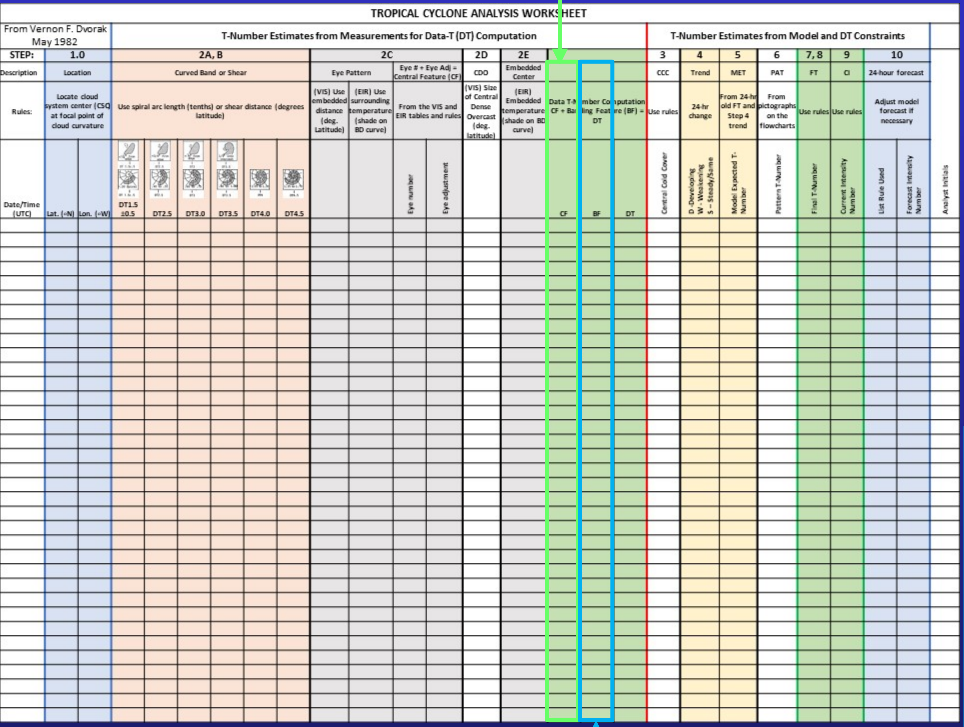
TROPICA CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements f r Data-T (DT) Computation																	T-Number Estimates from Model and DT Constraints								
STEP:	1.0		2A, B						2C				2D	2E				3	4	5	6	7, 8	9	10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Central F	ye Adj = ture (CF)	CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From th EIR table	VIS and and rules	(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

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

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																	T-Number Estimates from Model and DT Constraints								
STEP:	1.0		2A, B						2C				2D	2E				3	4	5	6	7, 8	9	10		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center				CCC	Trend	MET	PAT	FT	CI	24-hour forecast		
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT			Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT	Central Cold Cover	D - Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	Analyst Initials

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.**

Step 1 - Locate the Cloud System Center (CSC)

Locate the overall pattern center.

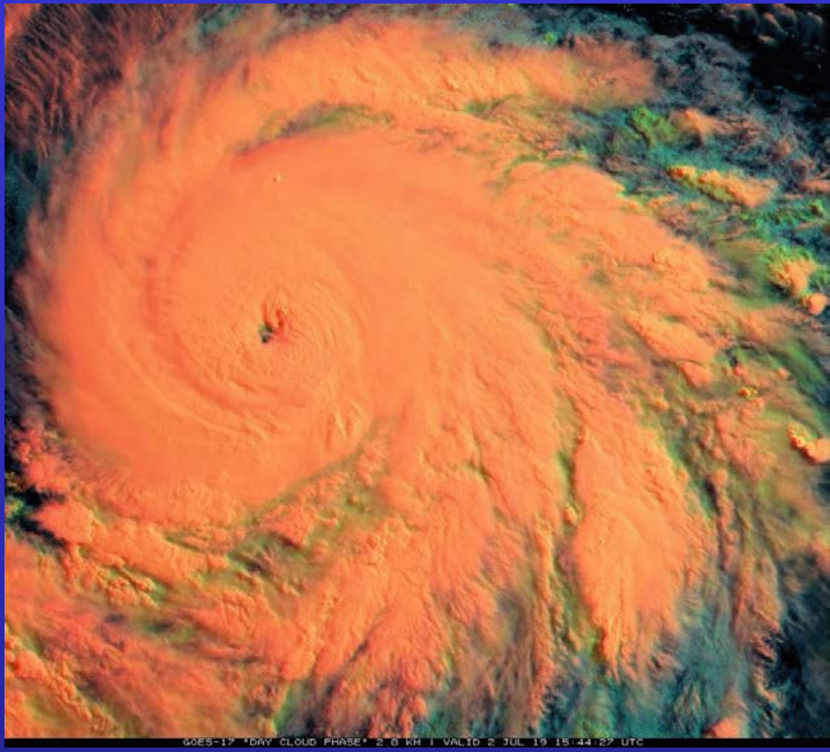
Look for small scale features.

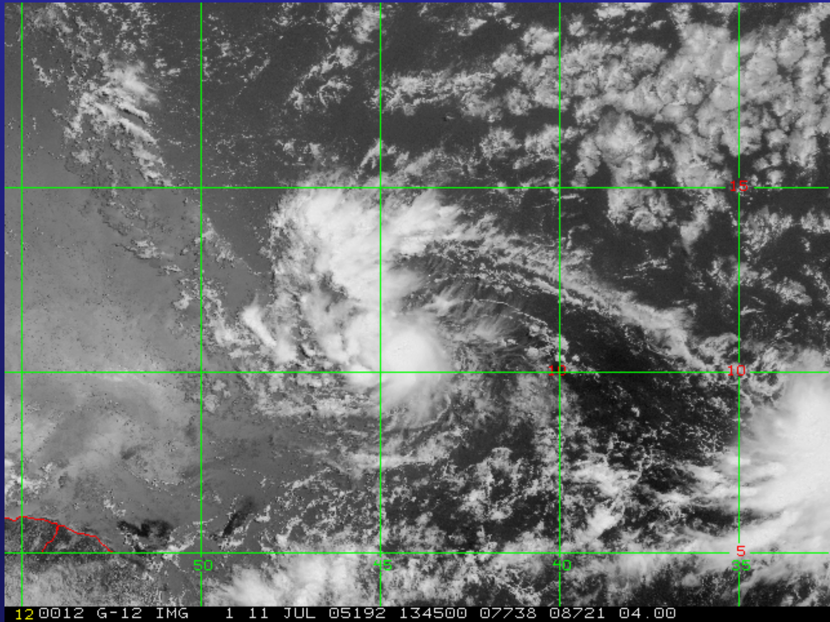
Compare center location with forecast.

Compare center with previous pattern center.

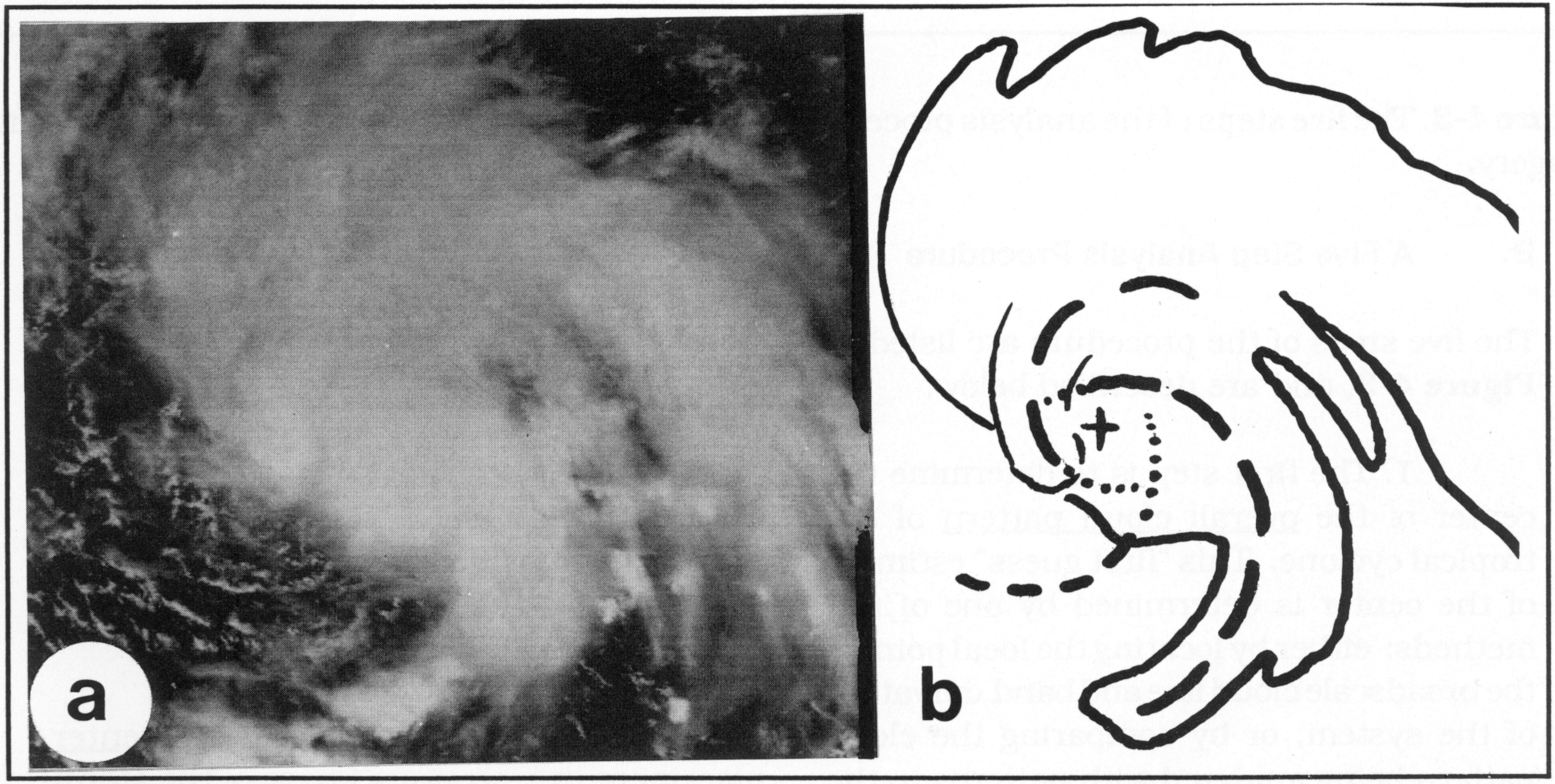
Make final location adjustments.

Looking for lowest possible center in terms of altitude (Surface center if possible).



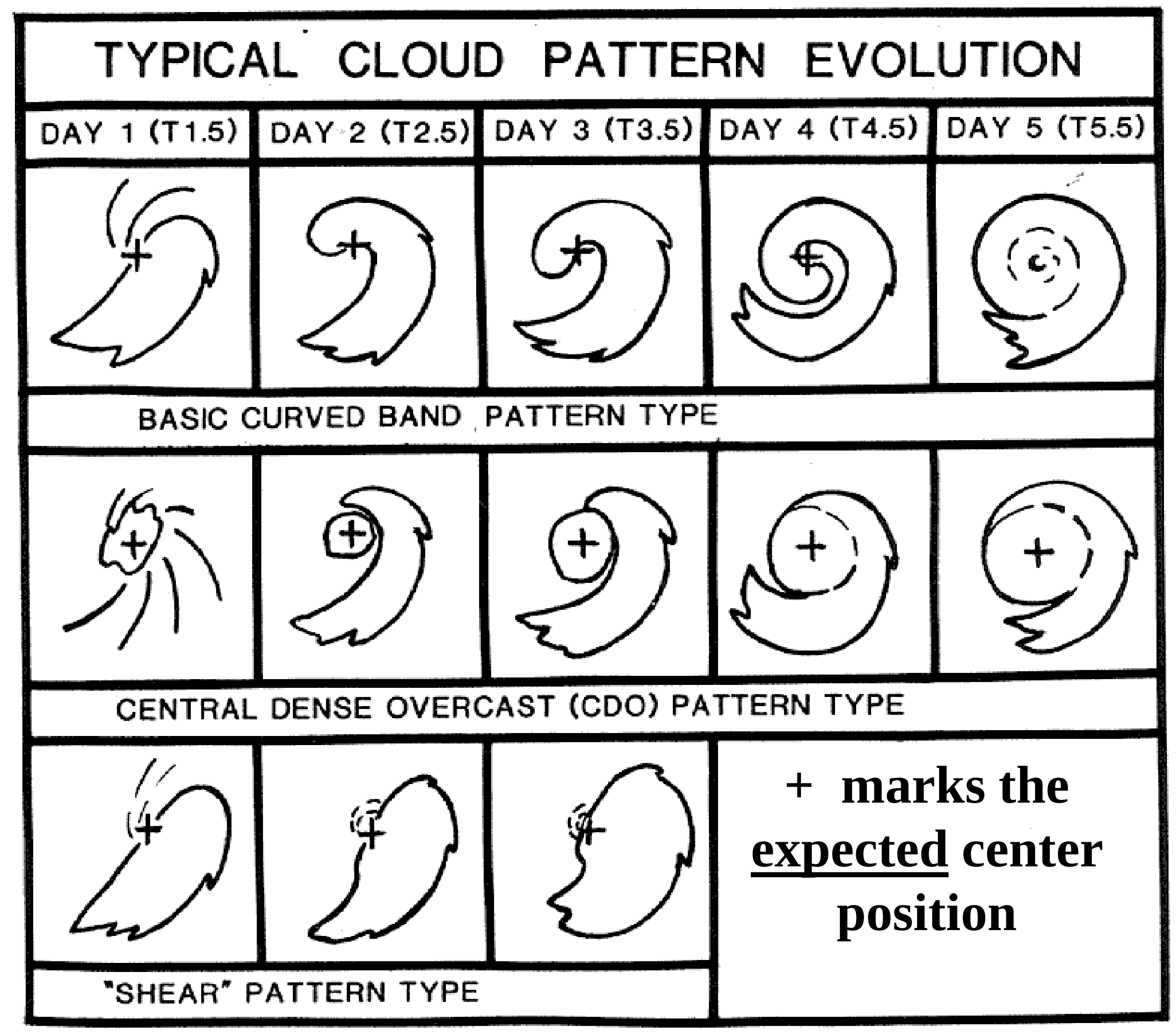


Step 1 – Locate the Cloud System Center (CSC)



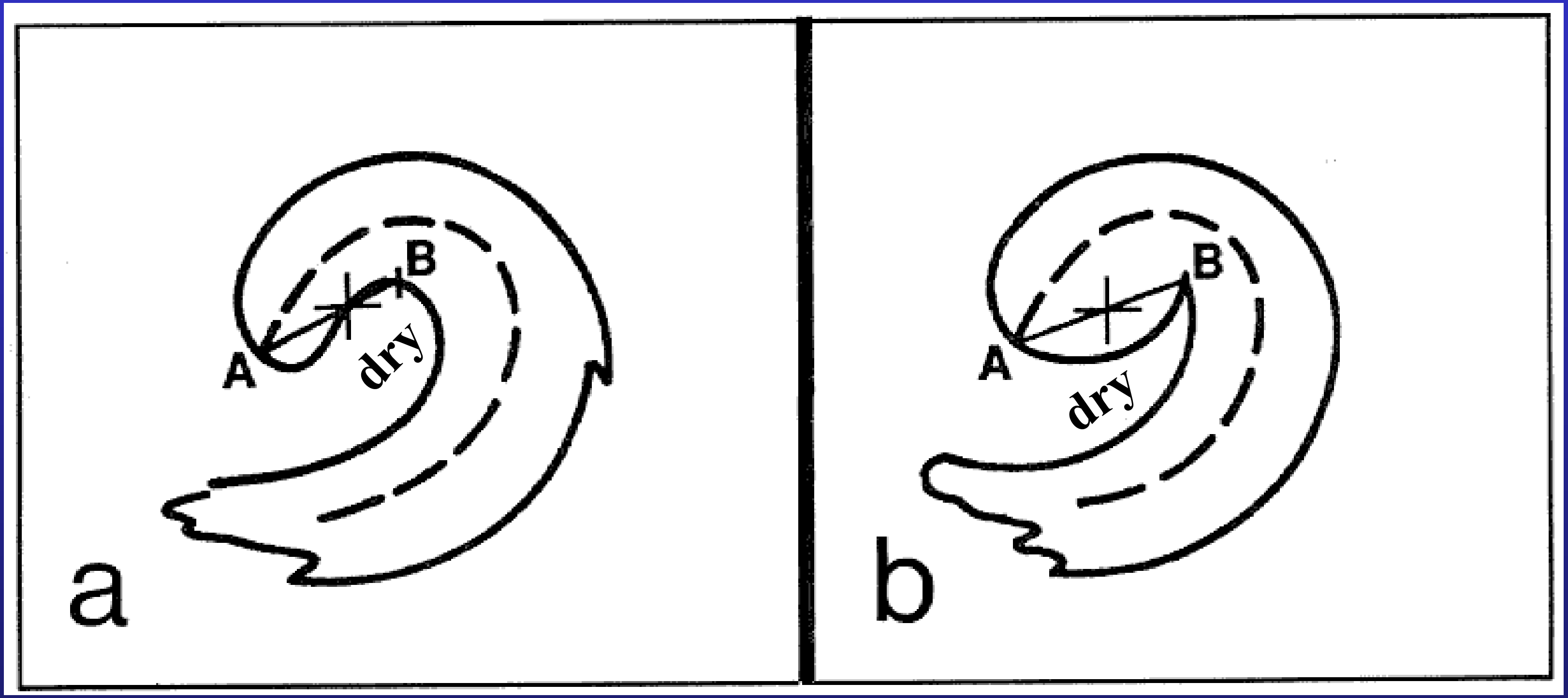
In this image the CSC is the focal point of curved cloud lines

Expected CSC Positions



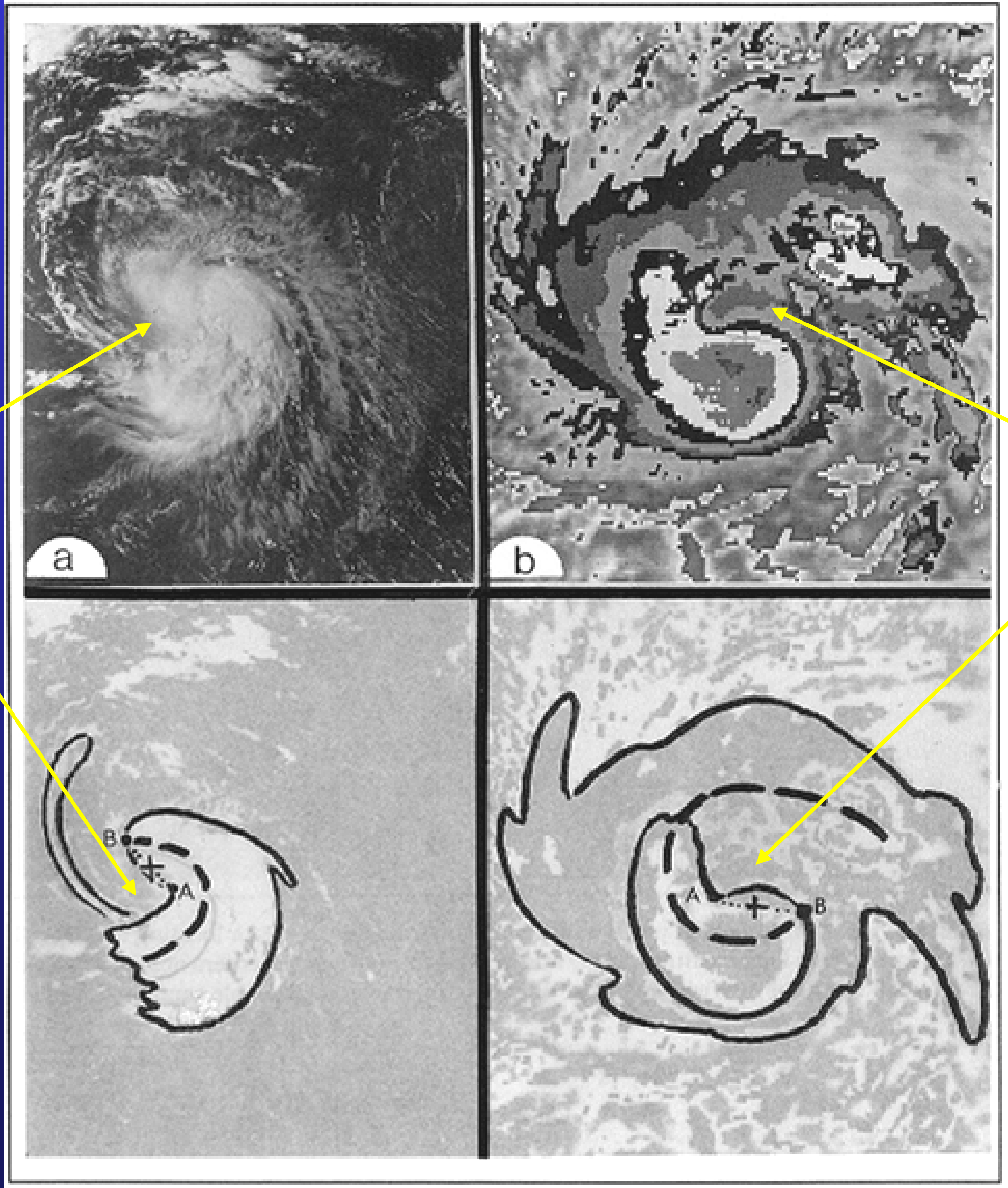
+ marks the <u>expected</u> center position

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

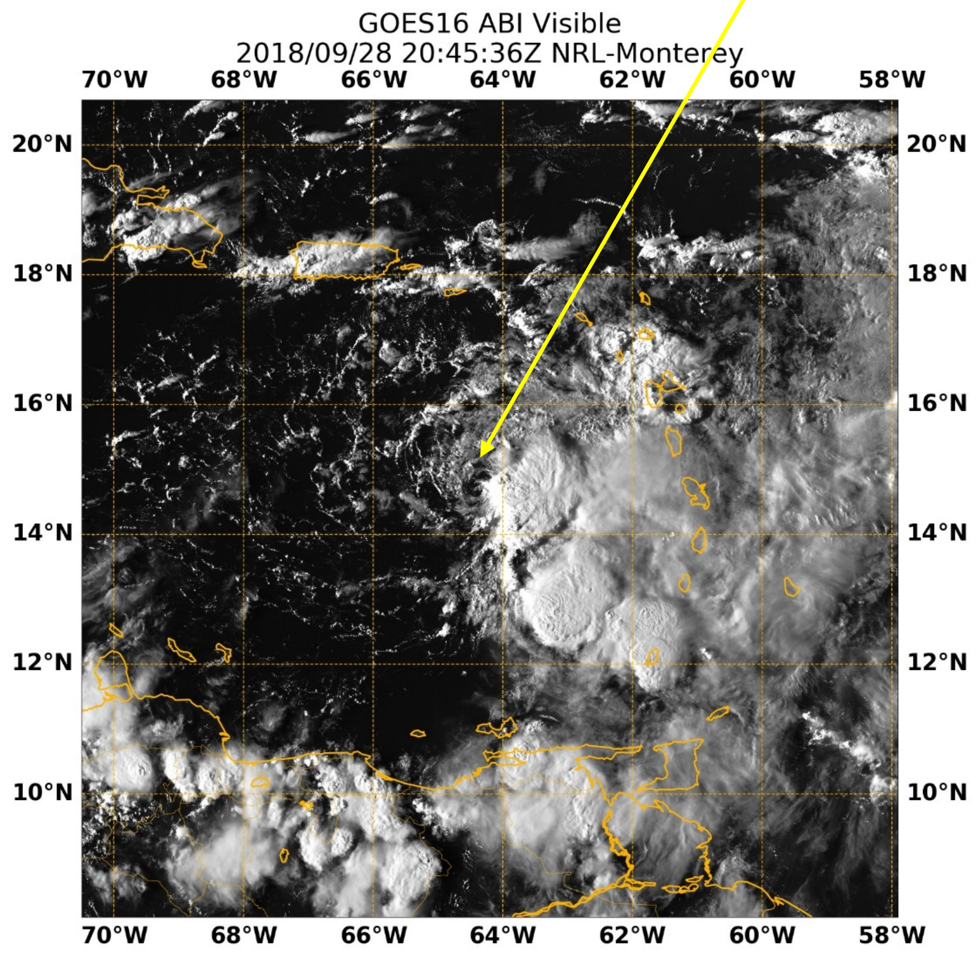


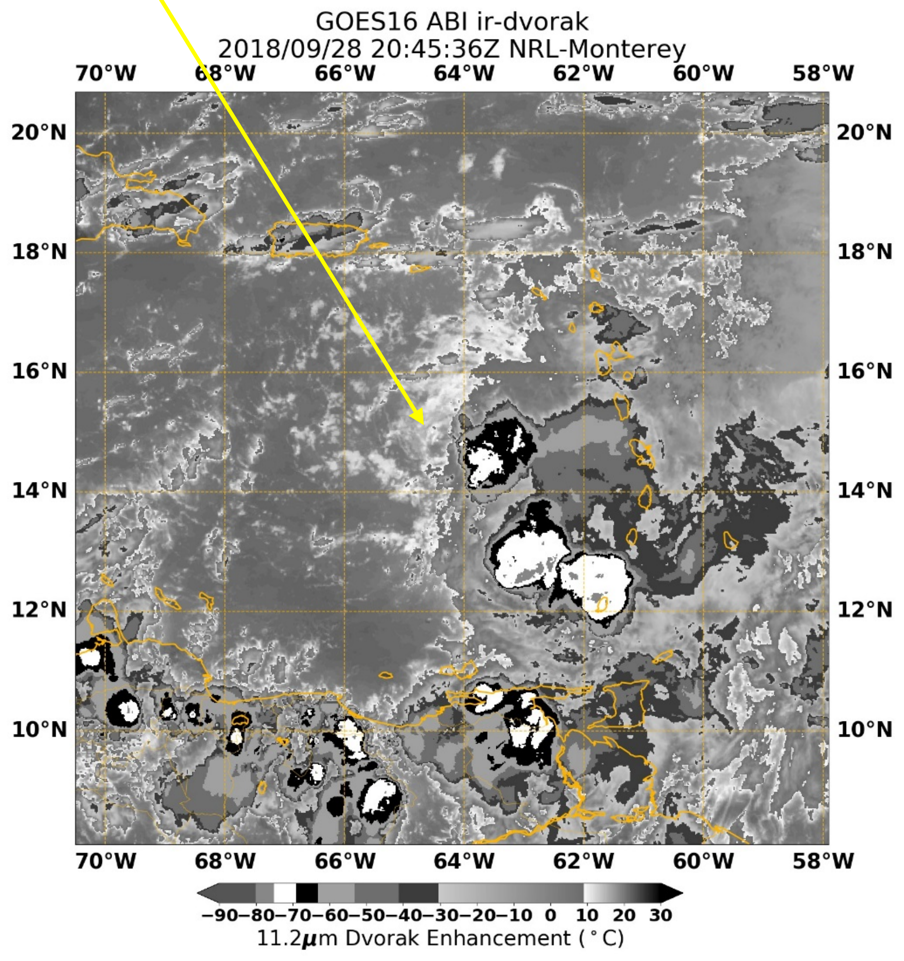
Dry slot

Dry slot

CSC Shear Pattern Example

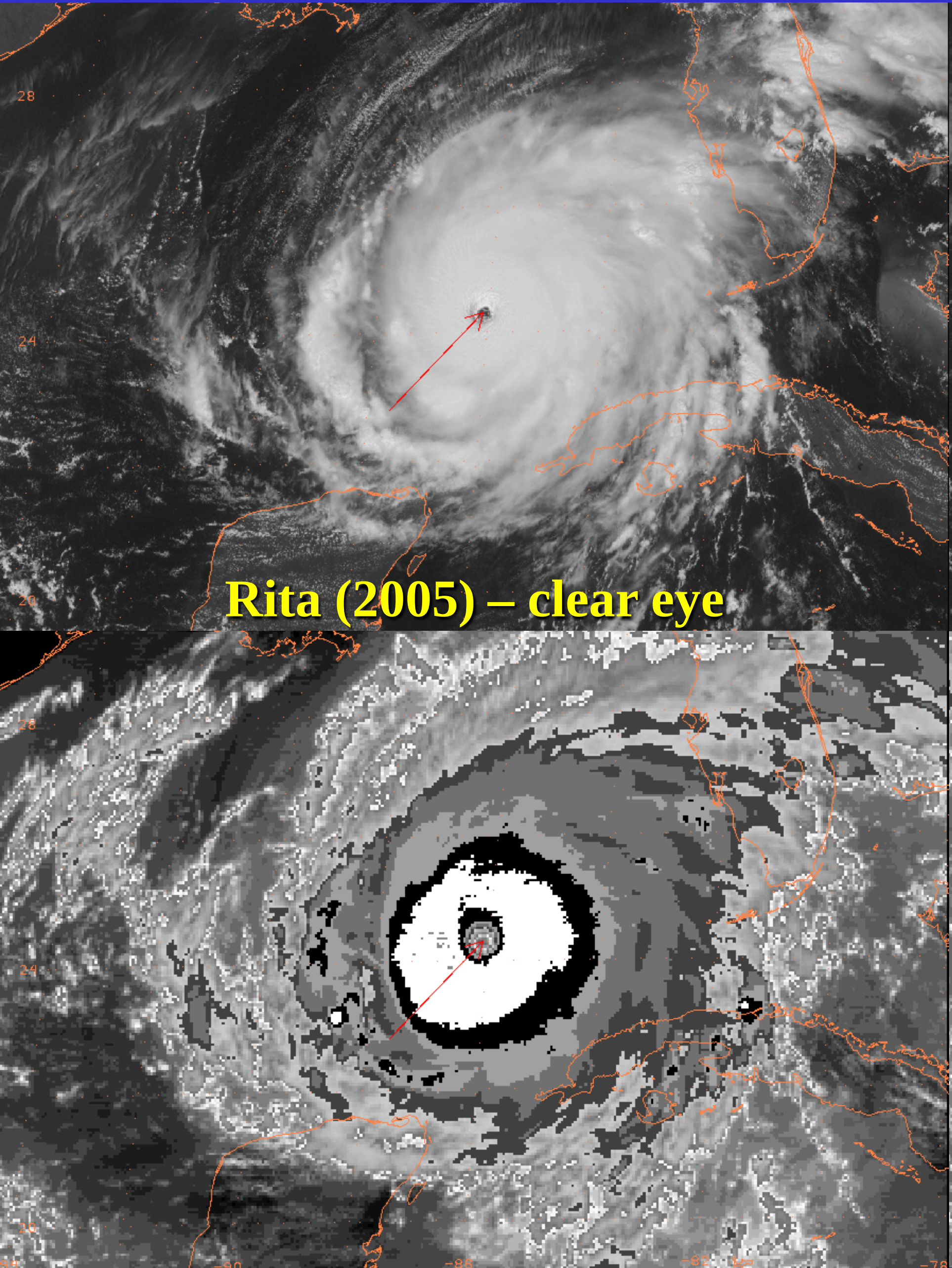
Low-level center

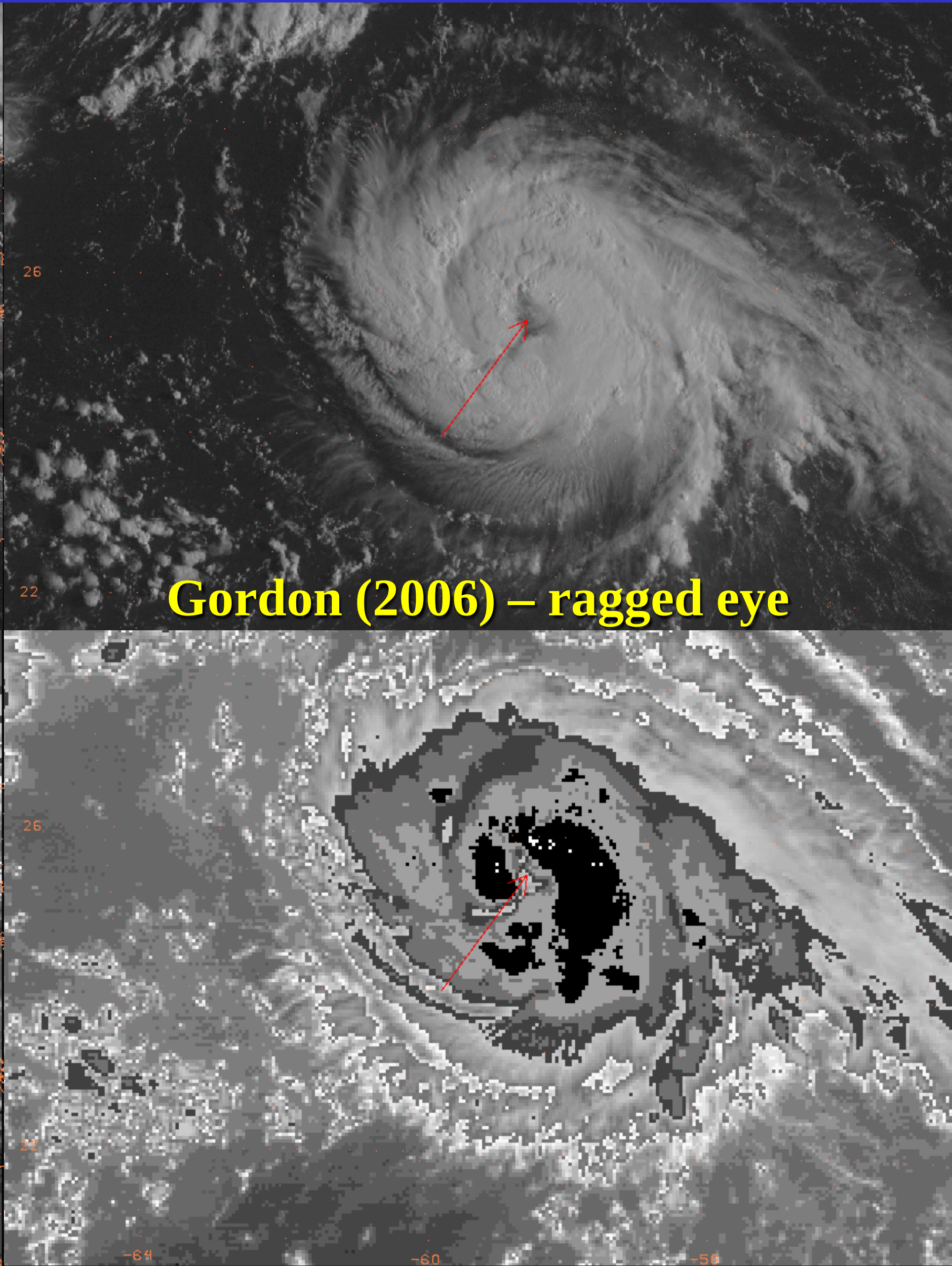




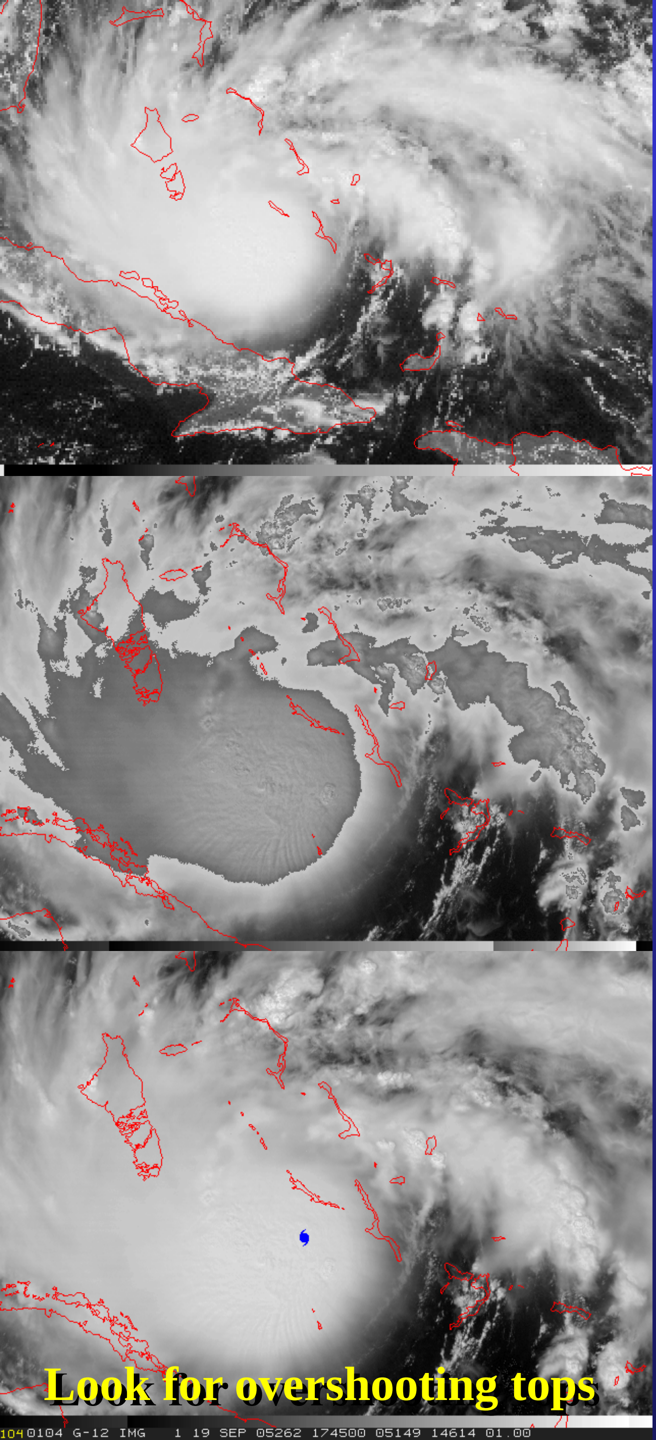
Good first guess position is the upshear side of the strongest convection

CSC Eye Pattern Examples

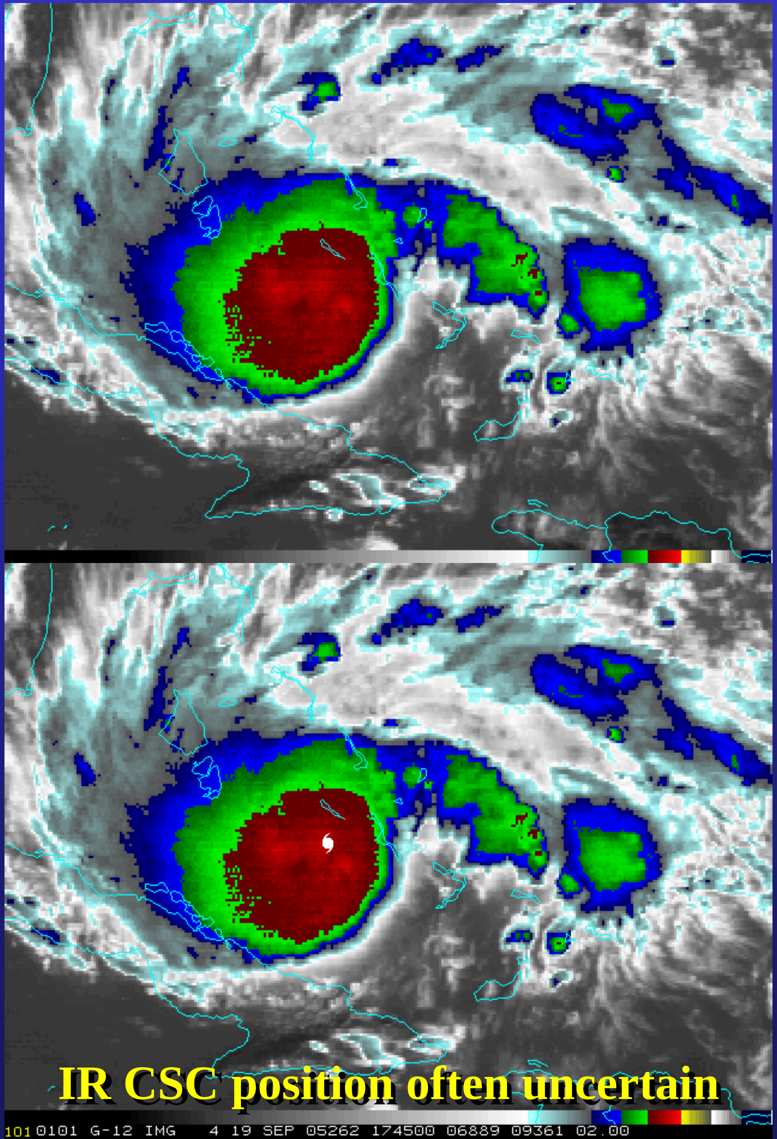

Rita (2005) – clear eye


Gordon (2006) – ragged eye

CDO/Embedded Center Pattern CSC Examples

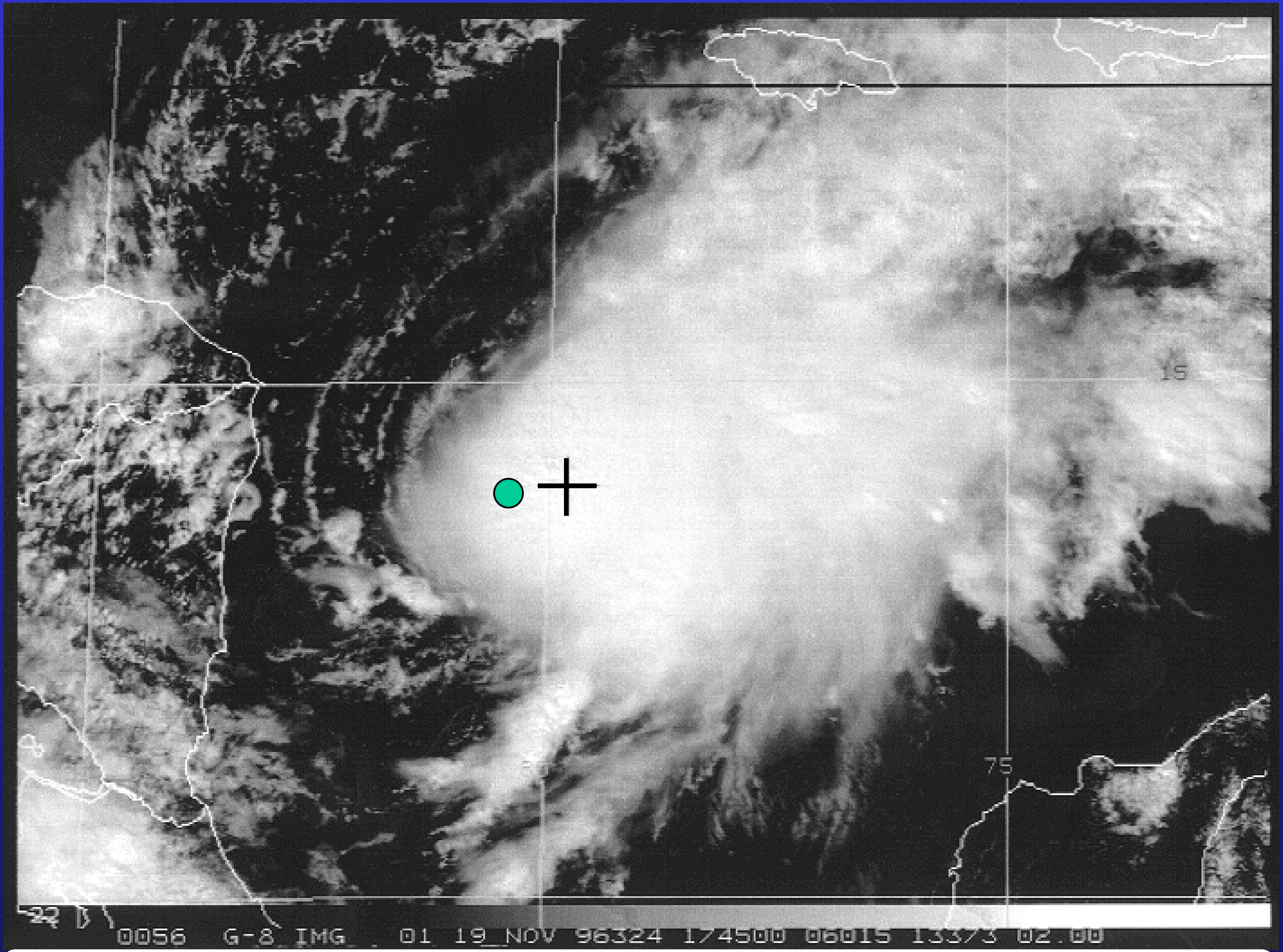


Look for overshooting tops



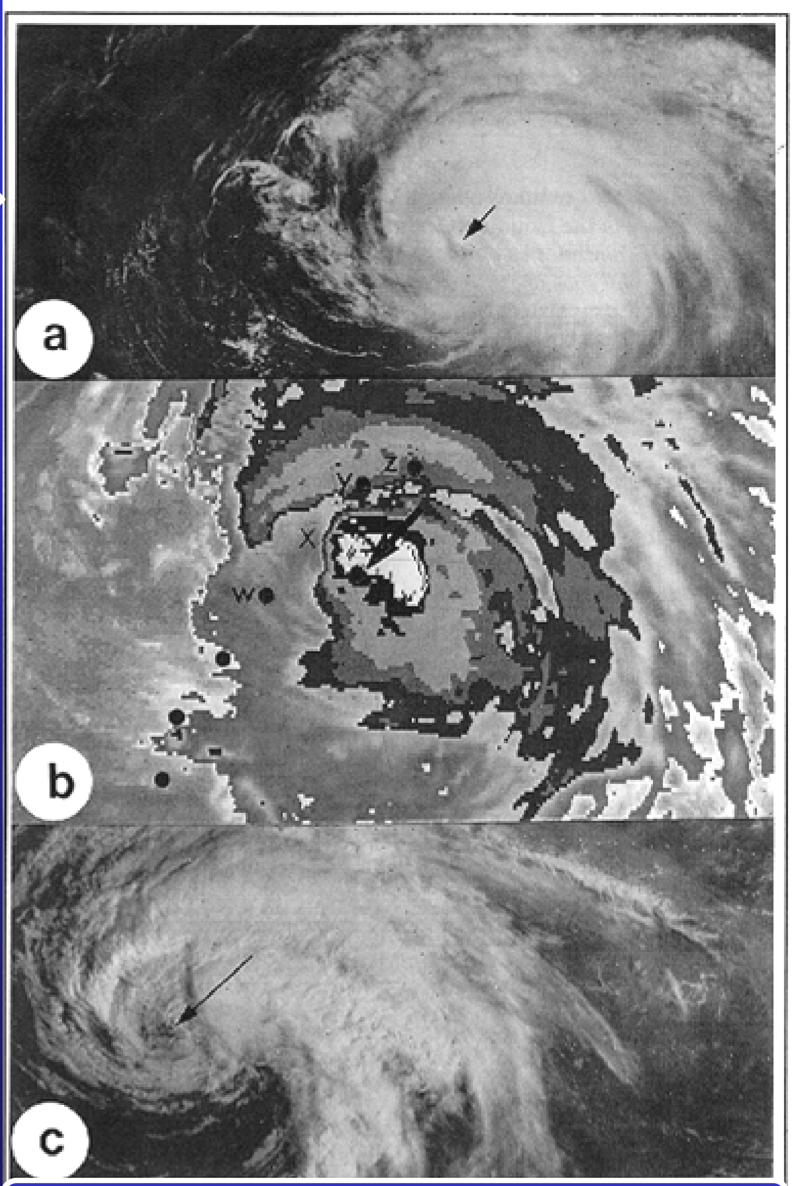
IR CSC position often uncertain

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)

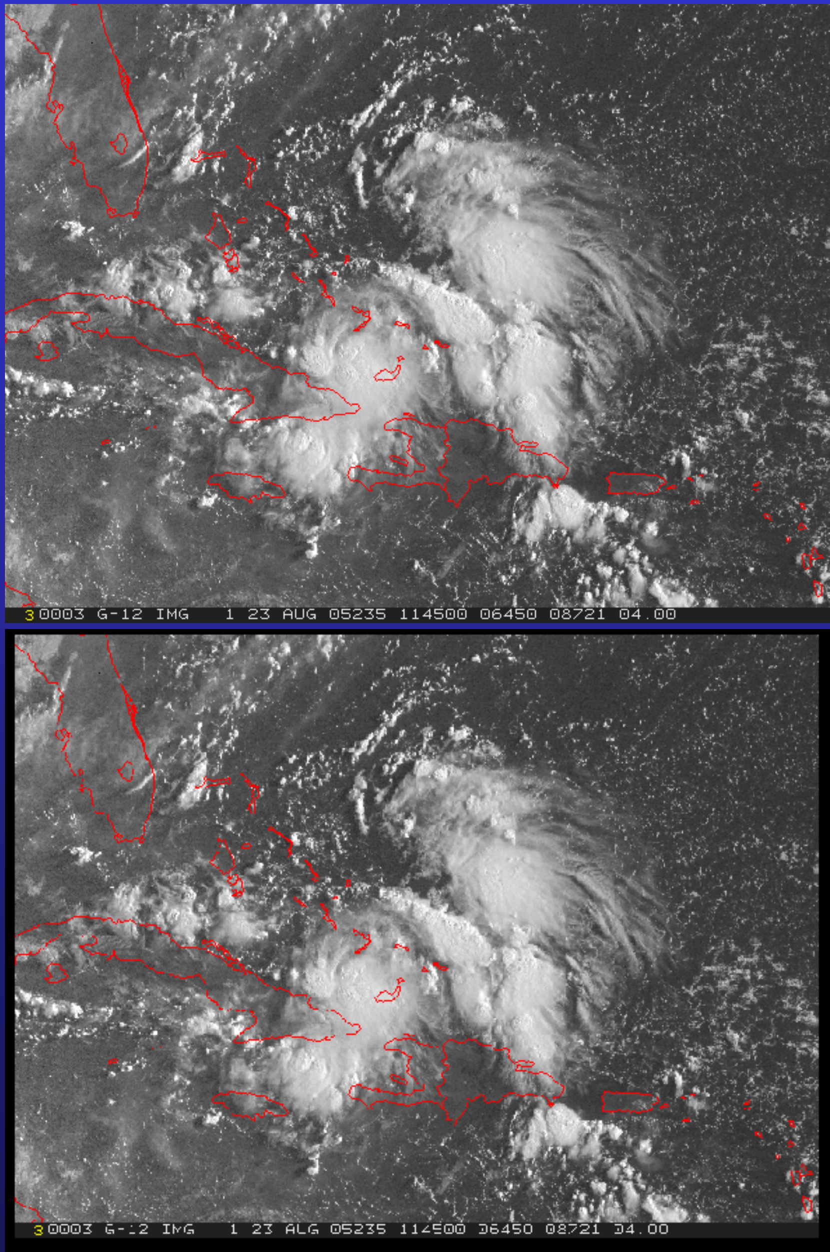
Animated Imagery

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!



Notes on Step 1

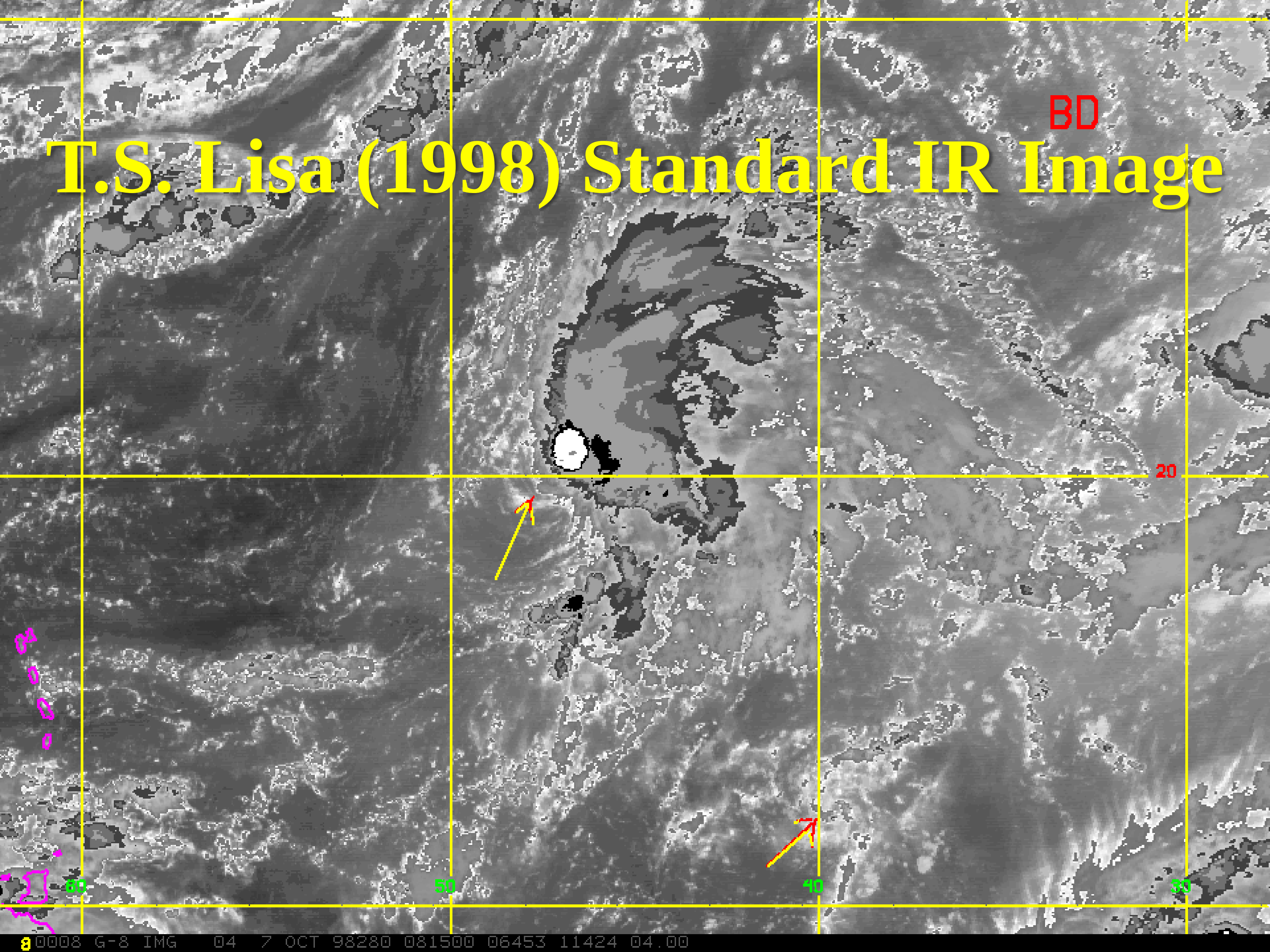
Other types of imagery (including microwave) and enhancements may be used in finding the CSC. These may be especially useful at night.

The CSC of a weak system is not always a closed circulation center.

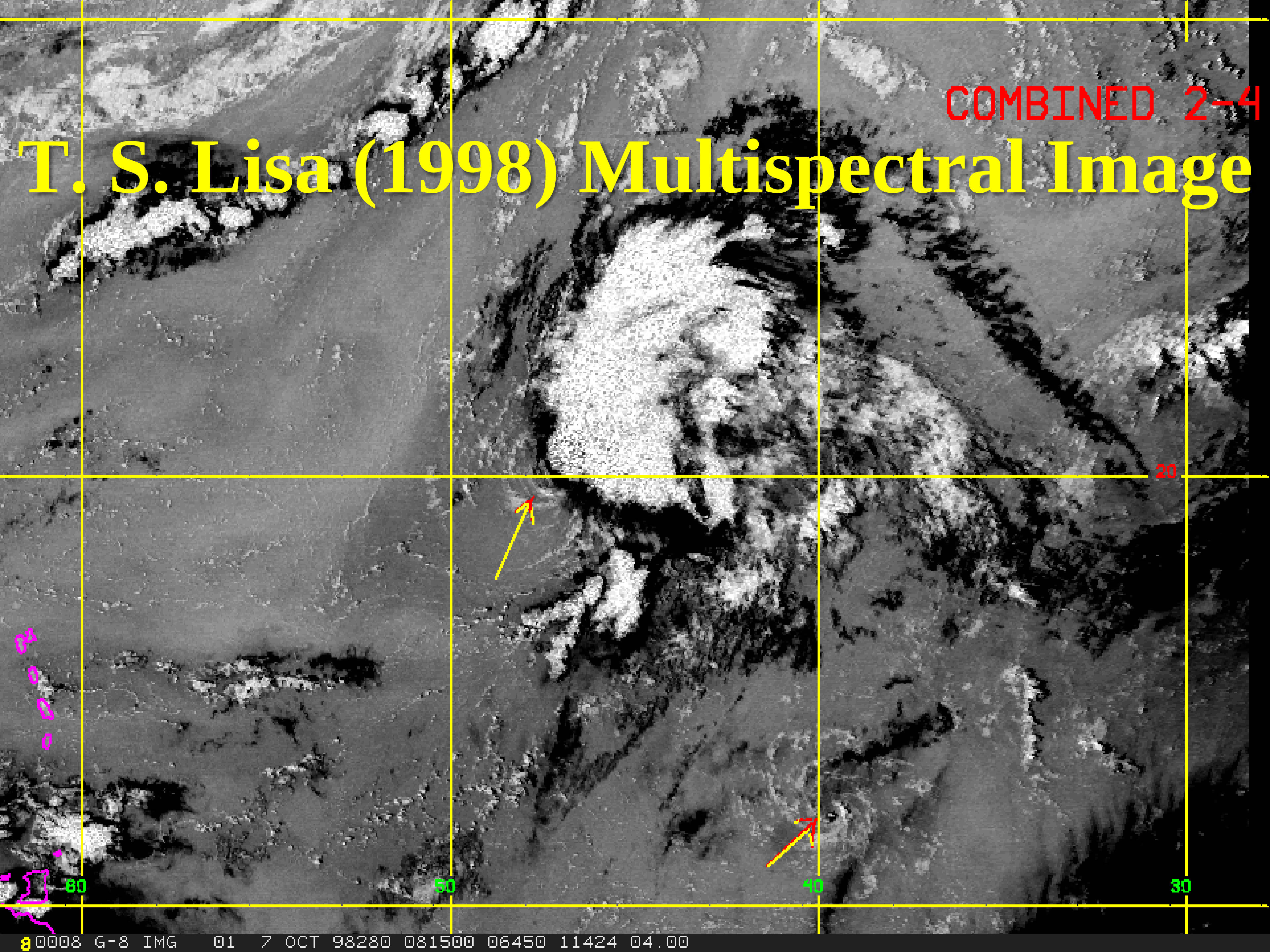
In a system with multiple centers, use a mean center position between the centers.

It’s hard to analyze the intensity if you don’t know where the cyclone is!

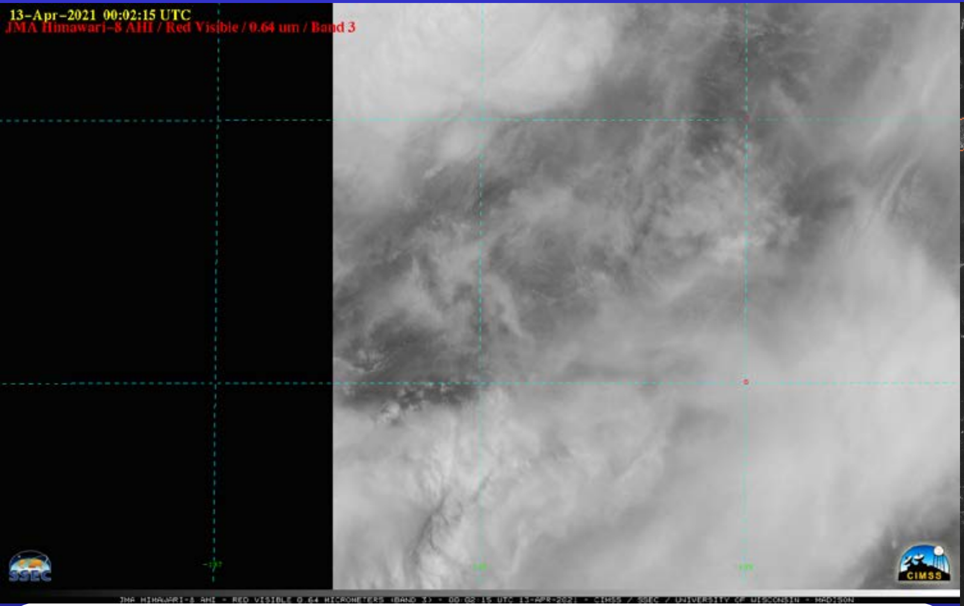
T.S. Lisa (1998) Standard IR Image



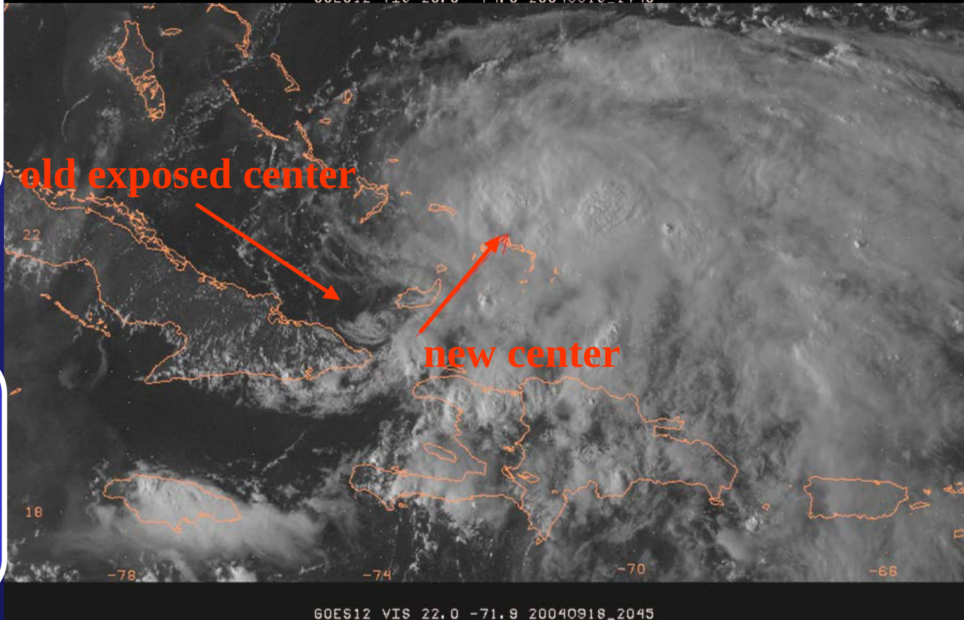
T. S. Lisa (1998) Multispectral Image



Cyclones with Multiple Centers



WESTPAC disturbance (2021) – Multiple swirls present – need to use a mean center (courtesy CIMSS)



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

Step 1A - A T1 classification can be given when…

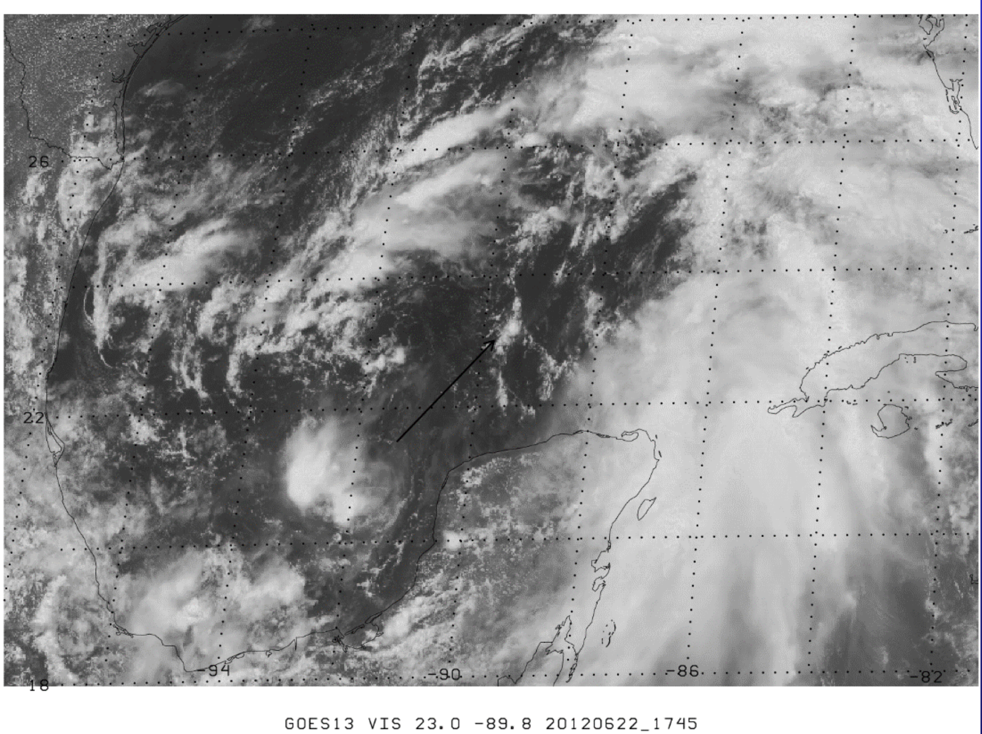
A convective cluster has persisted for 12 h or more.

The cluster has a CSC defined within a 2.5^{o} latitude wide or less area which has persisted for 6 h.

Associated convection is dark gray (DG) or colder on the Dvorak BD enhancement curve over an area $>1.5^{o}$ diameter less than 2^{o} 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 – Analyze the cyclone cloud pattern

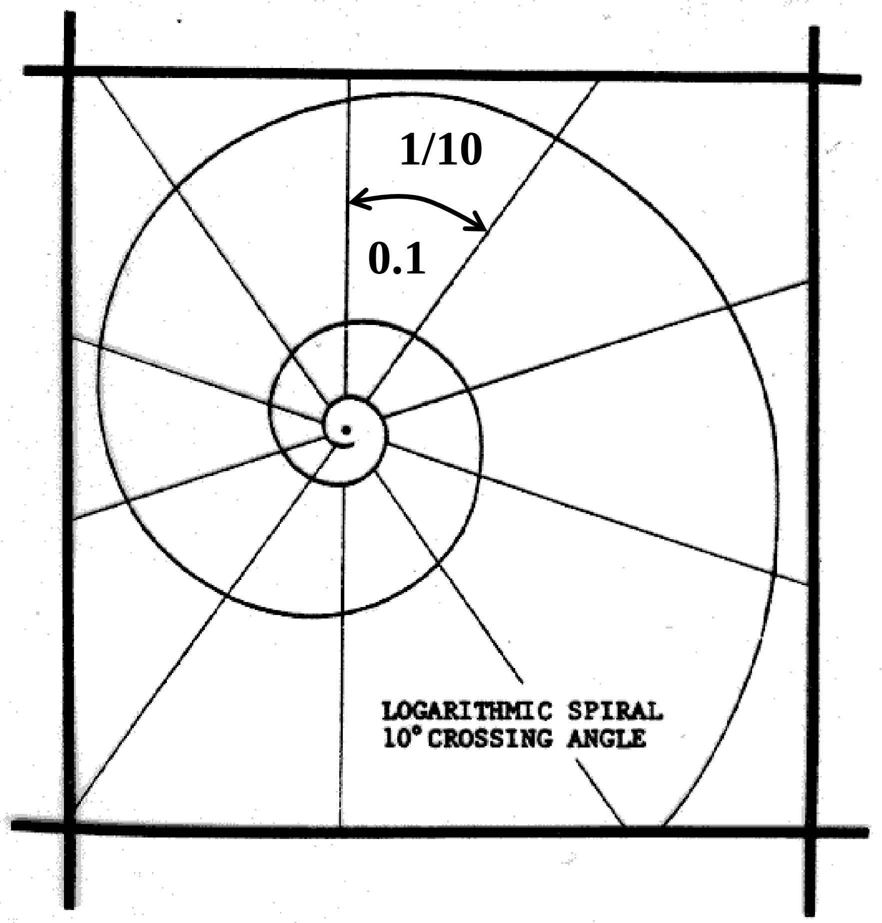
The cloud pattern analysis produces the Data-T (DT) number intensity estimate.

Tool: Log 10° 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.

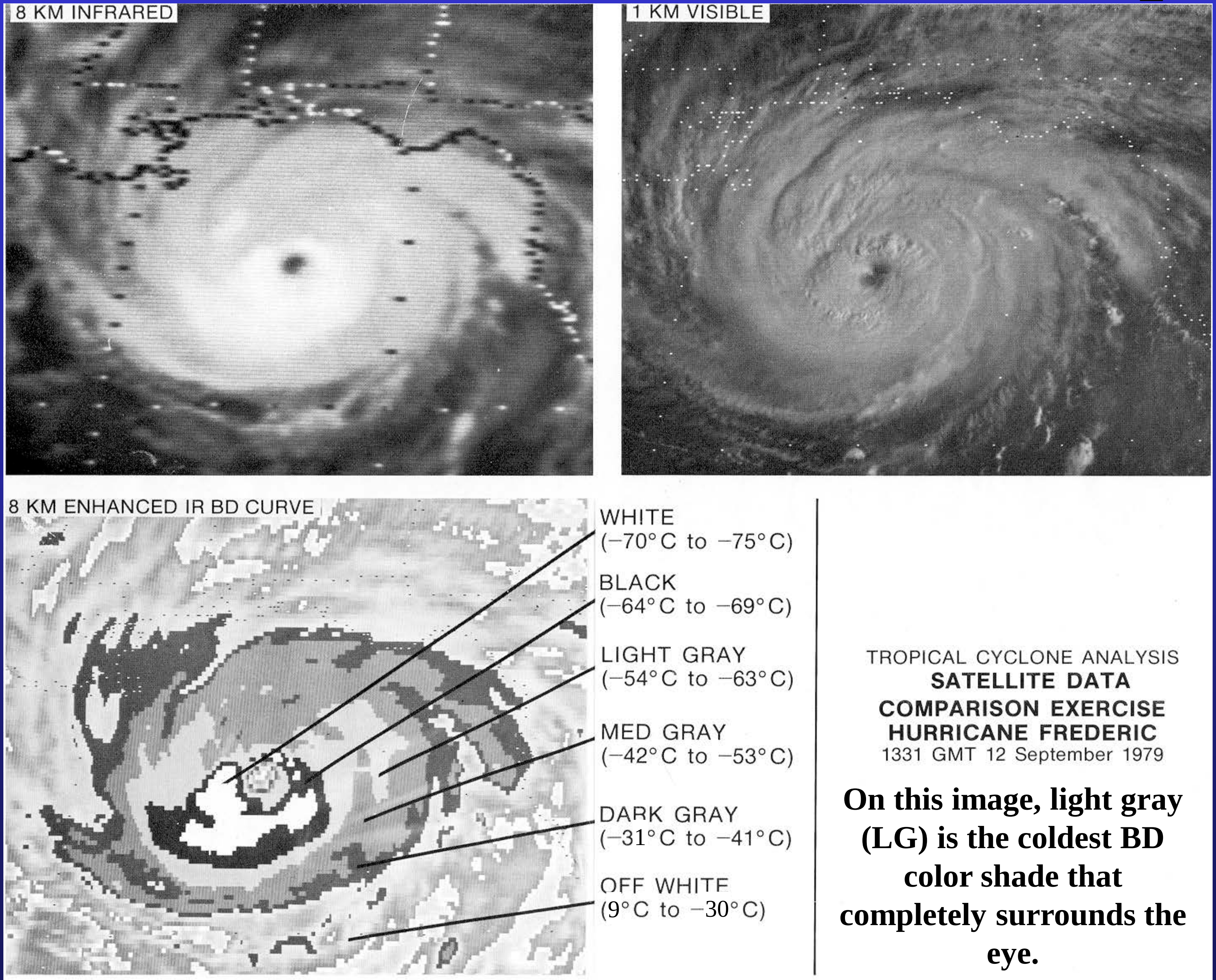


BD Enhancement Curve

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

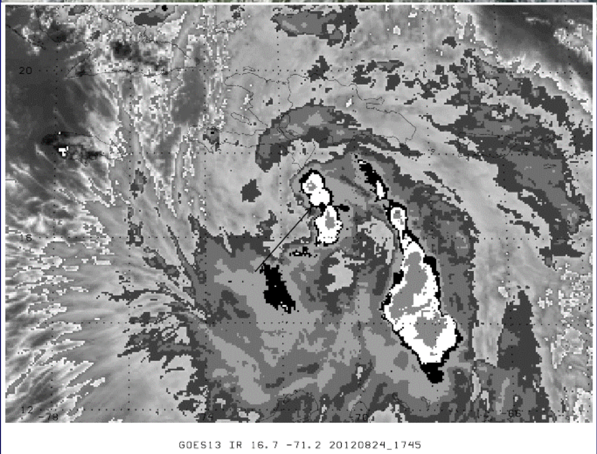
Fit the spiral parallel to the inner edge of the band (VIS) or to the coldest tops in the band (IR)

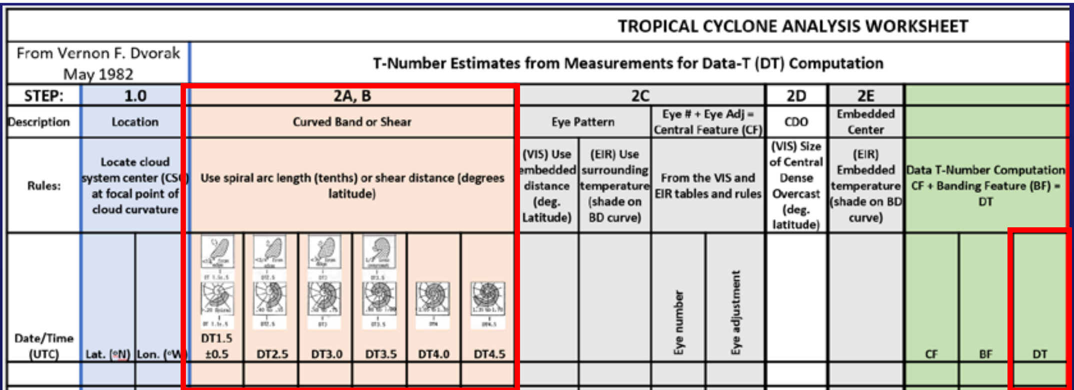
Measure only the primary band of the cyclone - other bands don't count

Endpoints of bands can be rather subjective

Important: The center of the log 10º spiral is usually <u>not</u> the center of the cyclone!

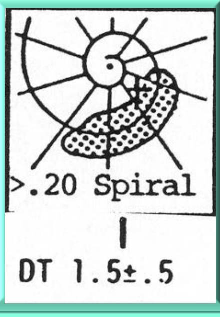
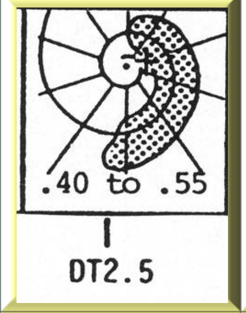
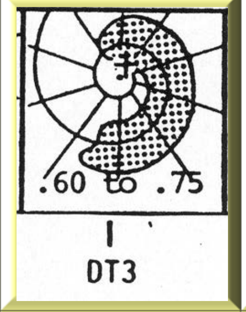
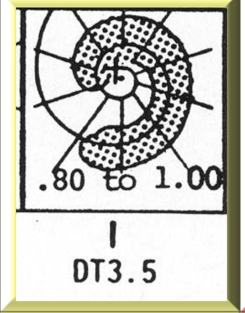
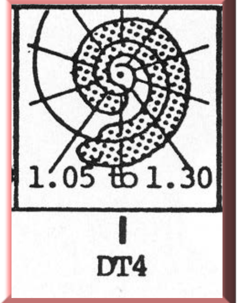
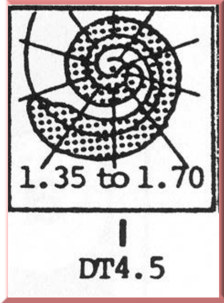
Note: Nature does not always produce bands with 10 degrees crossing angles ☺





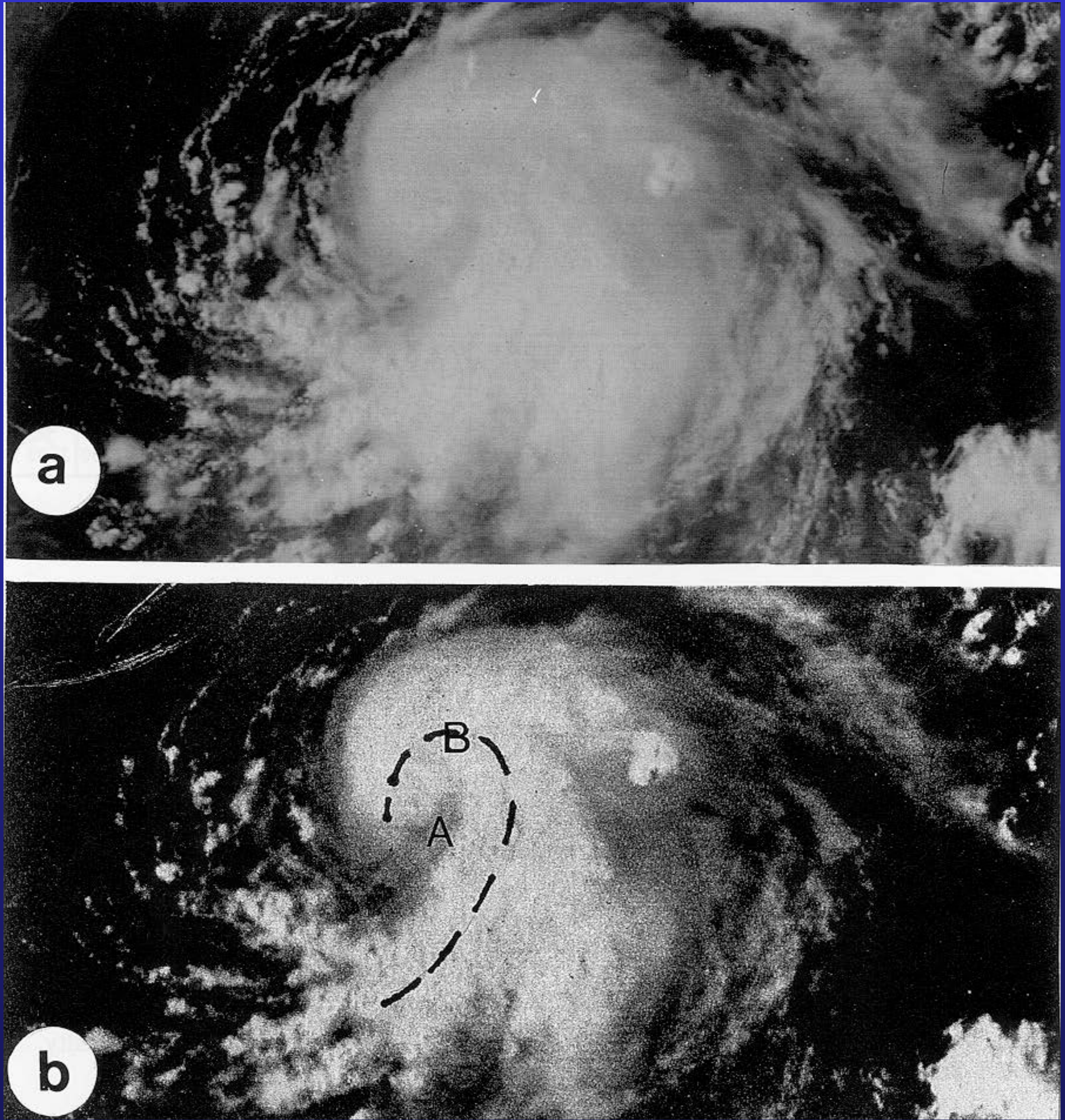
								TROPICAL CYCLONE ANALYSIS WORKSHEET								
From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation													
STEP:	1.0		2A, B						2C				2D	2E		
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center		
Rules:	Locate cloud system center (CS at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use mbedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT	
Date/Time (UTC)	Lat. (°N)	Lon. (°W	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT

Step 2A - Curved Band Patterns

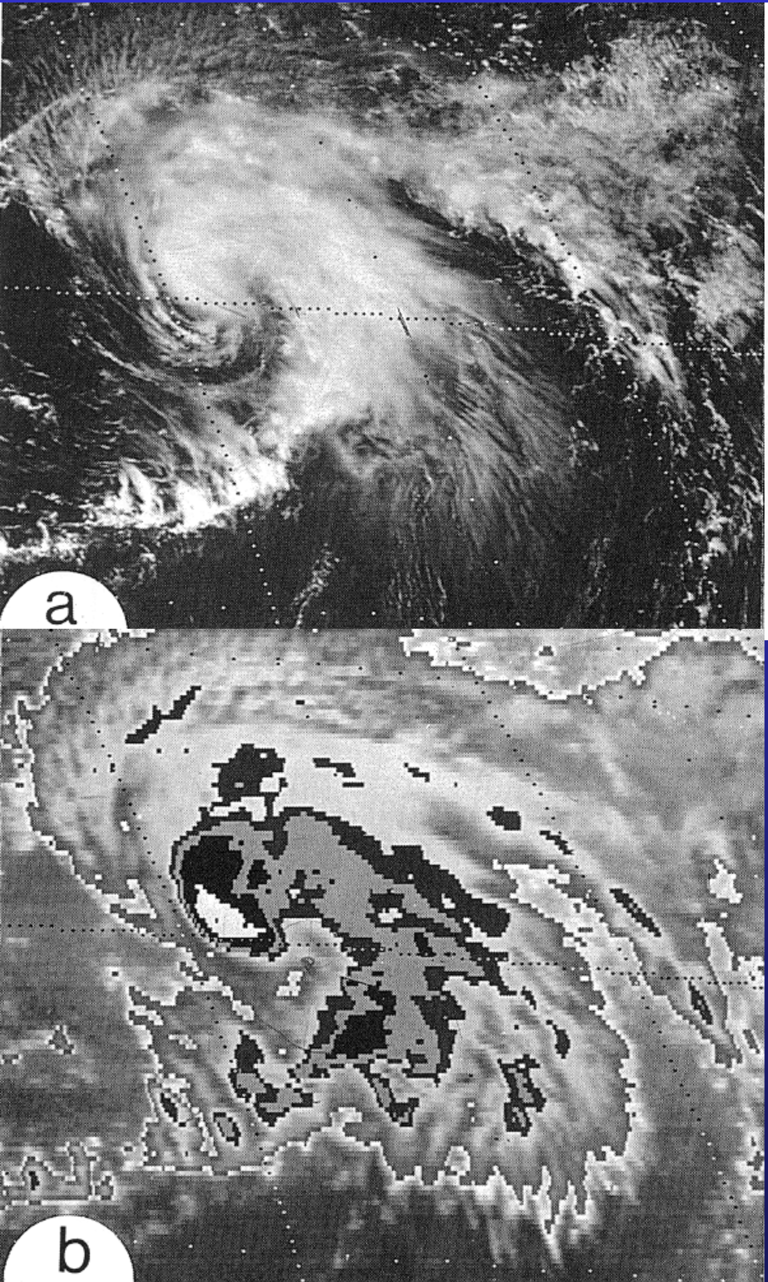
Flow chart images						
Spiral arc distance (tenths along log 10° spiral)	**0.20 - 0.35**	**0.40 - 0.55**	**0.60 - 0.75**	**0.80 - 1.00**	**1.05 - 1.30**	**1.35 - 1.70**
Data-T Number (DT)	**1.0 to 2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**

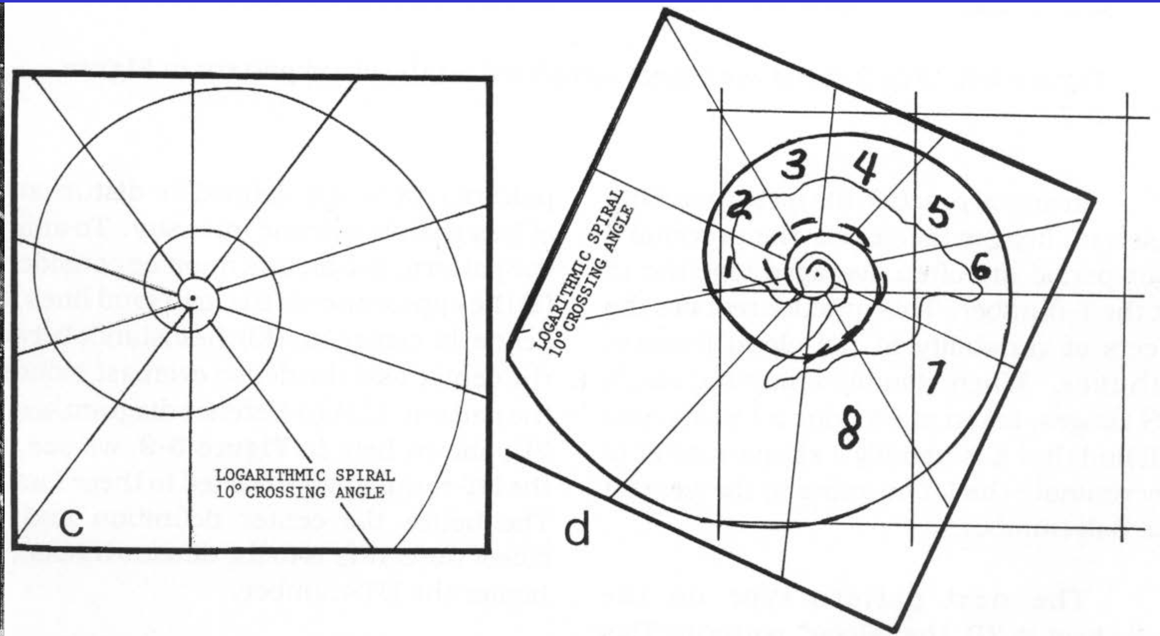
These patterns are for both visible and infrared imagery.
Use banding eyes in Step 2C for unusual band widths and lengths in visible imagery.

Step 2A - Curved Band Example

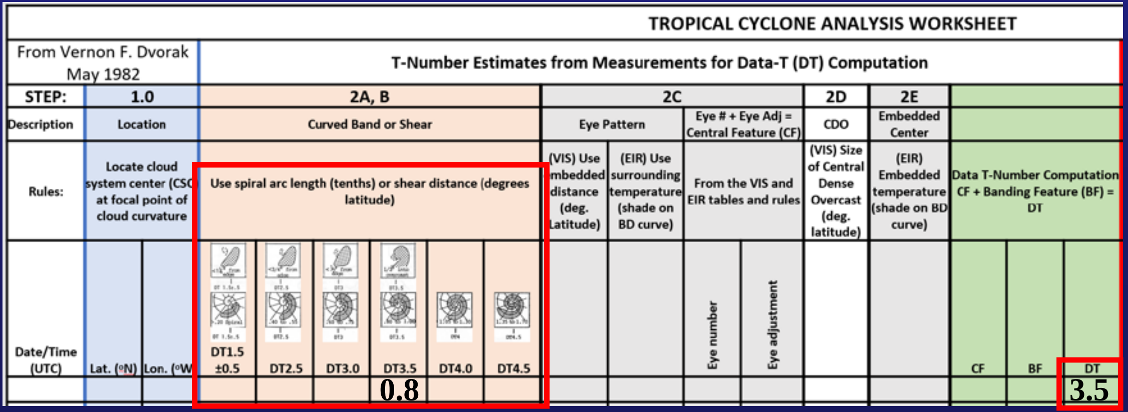


Step 2A - Measuring Curved Bands





0.8 Banding - DT=3.5



TROPICAL CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation														
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use mbedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
						0.8											3.5

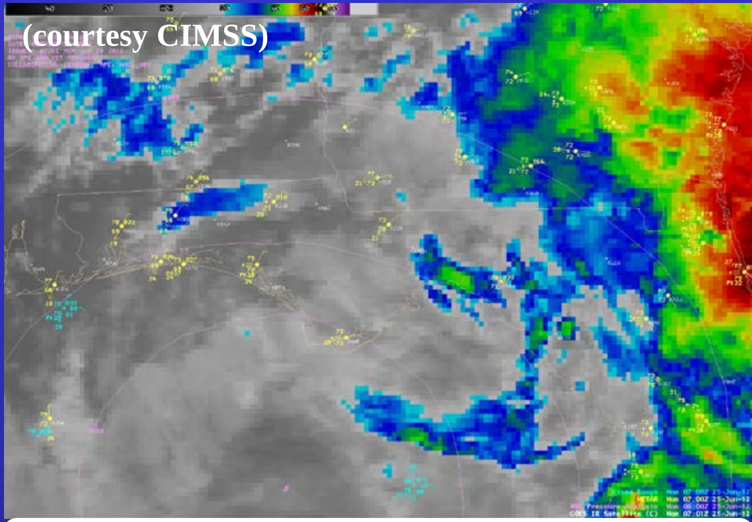
Step 2B – Measuring Shear Patterns

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).

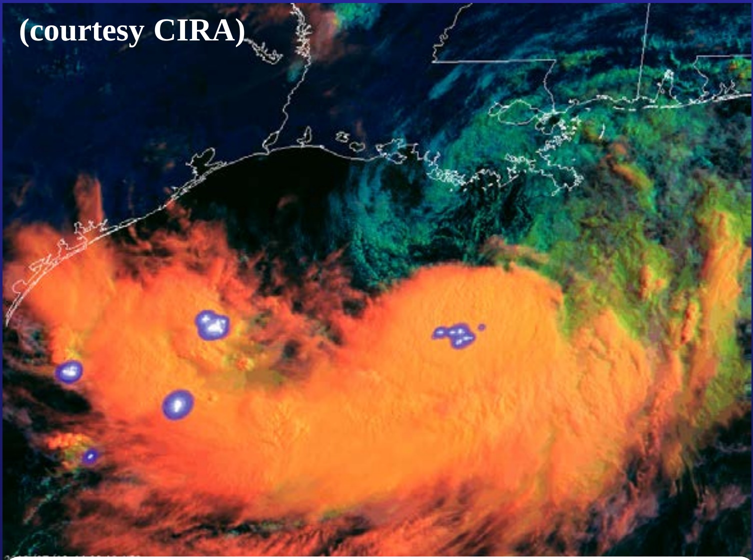
The edge of the convection can be rather subjective.

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.*

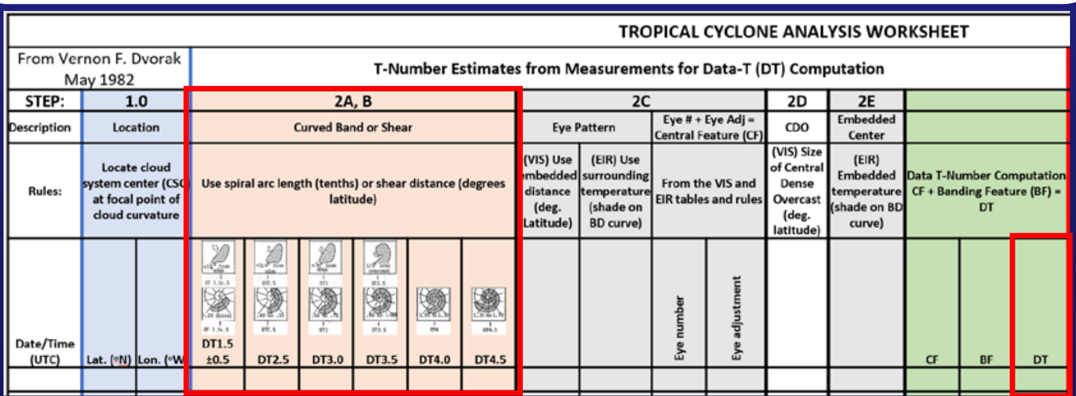
Shear pattern convection can dissipate between pulses/bursts to the point where a DT cannot be determined. The Pattern-T or Model Expected-T can be used to classify such systems.


(courtesy CIMSS)

Debby (2012) convective burst

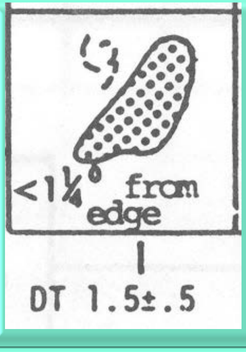
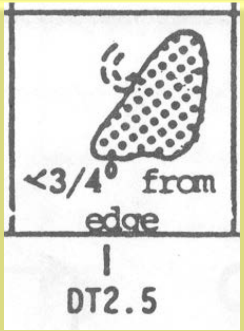
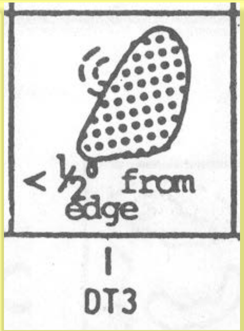
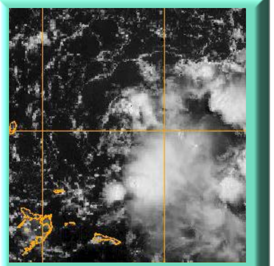
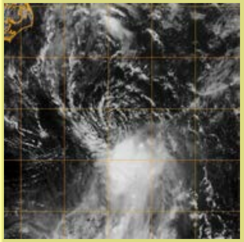
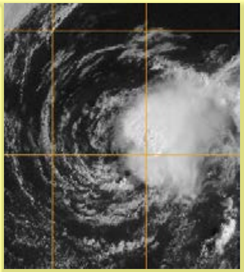
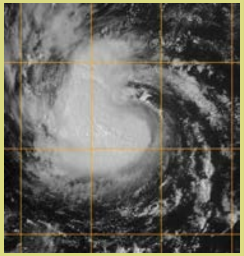

(courtesy CIRA)

Barry (2019) Cloud Phase RGB


TROPICAL CYCLONE ANALYSIS WORKSHEET

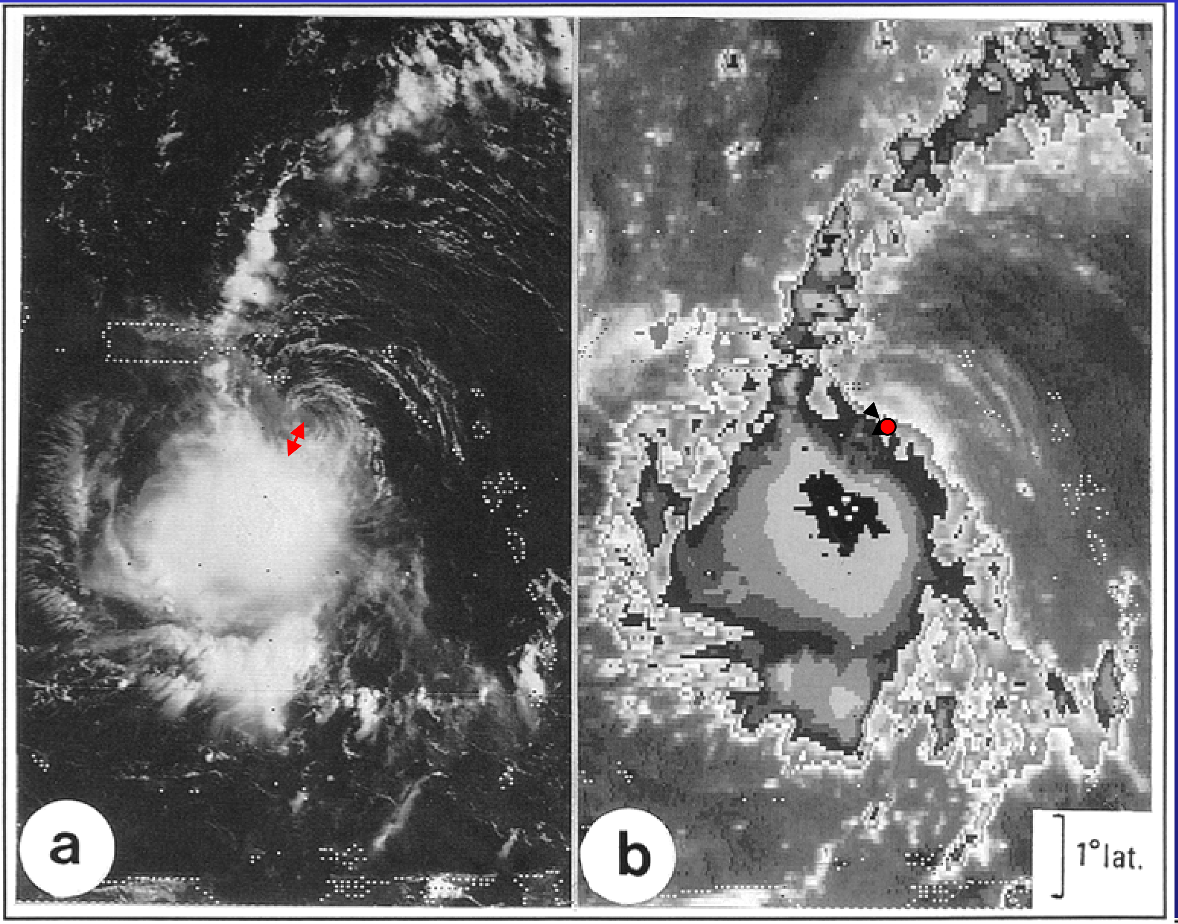
From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation														
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use mbedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (°N)	Lon. (°W	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT

Step 2B Shear Patterns

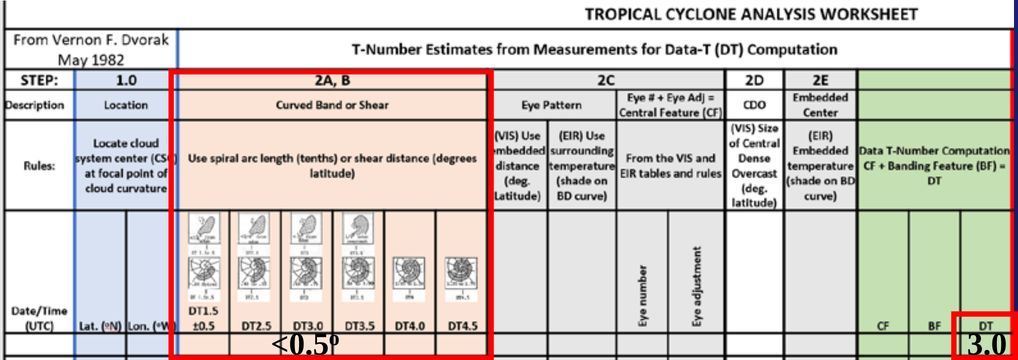
Flow chart images				
Distance from edge of convection or DG (tenths of deg latitude)	1.25 – 0.75	0.74 – 0.50	0.49 from Cnvtn to 0.32 into Cnvtn	>0.33 into Cnvtn
Data-T Number (DT)	1.0 to 2.0	2.5	3.0	3.5
Satellite Images				

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

From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation														
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CS at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use mbedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (°N)	Lon. (°W	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
					<0.5°												3.0

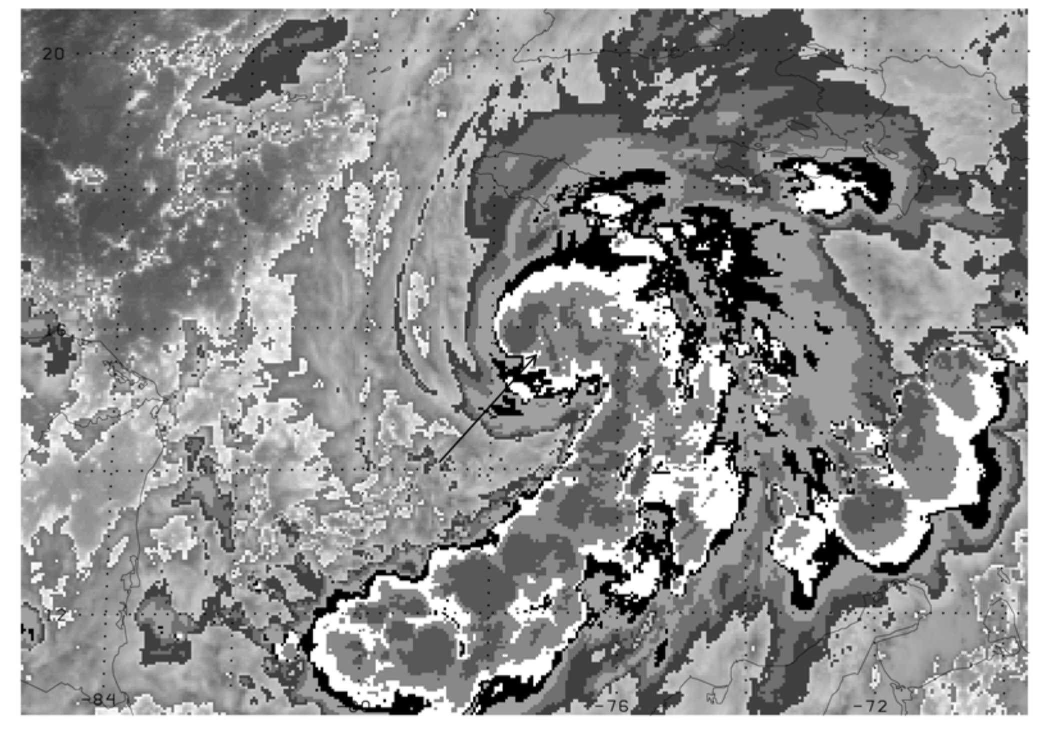
Notes on Steps 2A and 2B

When available, VIS curved band and shear patterns are preferable to their IR counterparts.

Curved bands and shear patterns directly produce DT numbers.

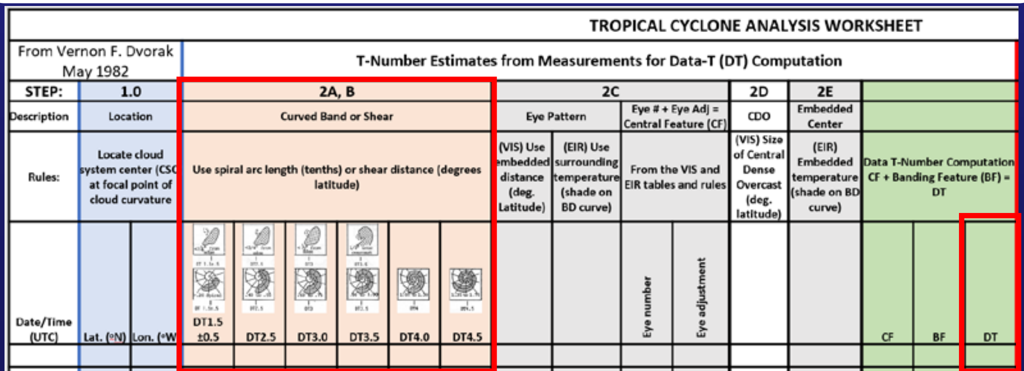
The measurements are the same for both VIS and IR imagery.

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

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT

Step 2C – Measuring Eye Patterns Some Assembly Required!

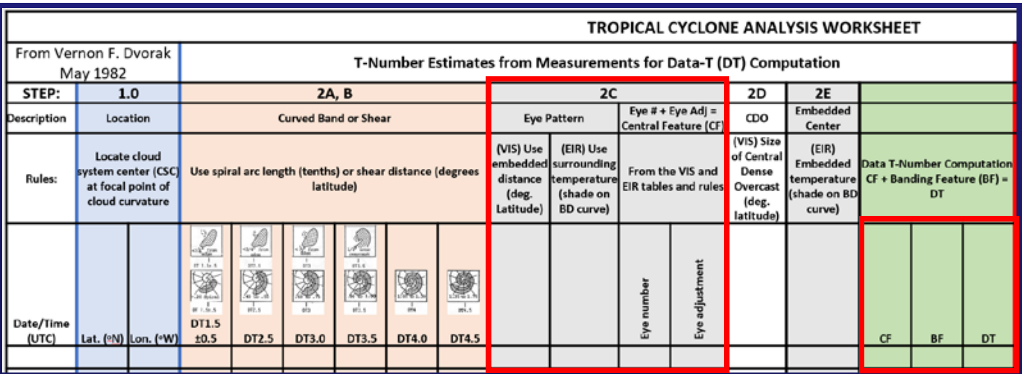
Find the eye number (E-number).

Perform an Eye Adjustment.

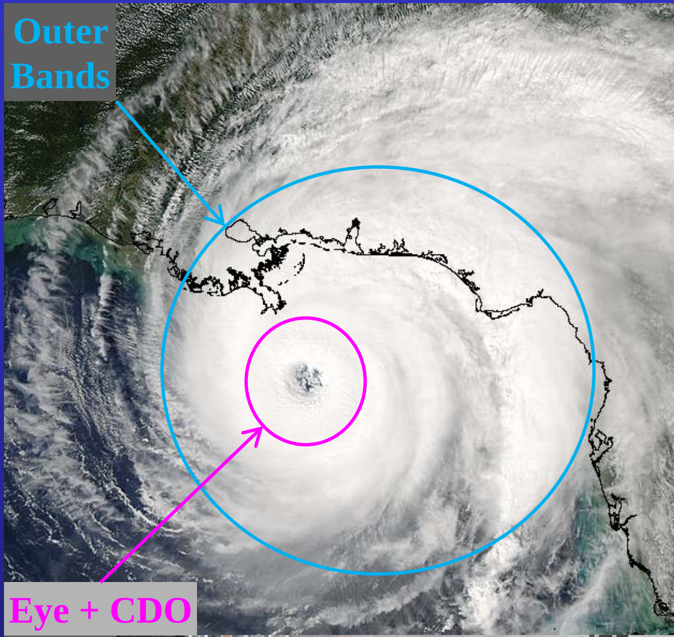
Create the Central Feature (CF) number from the E-number and Eye Adjustment.

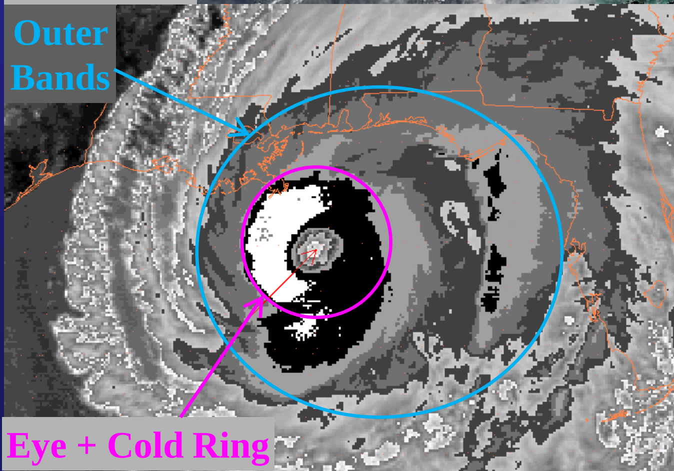
Add applicable banding features (BF) to the CF number to get the DT number.

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																	
From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation														
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT



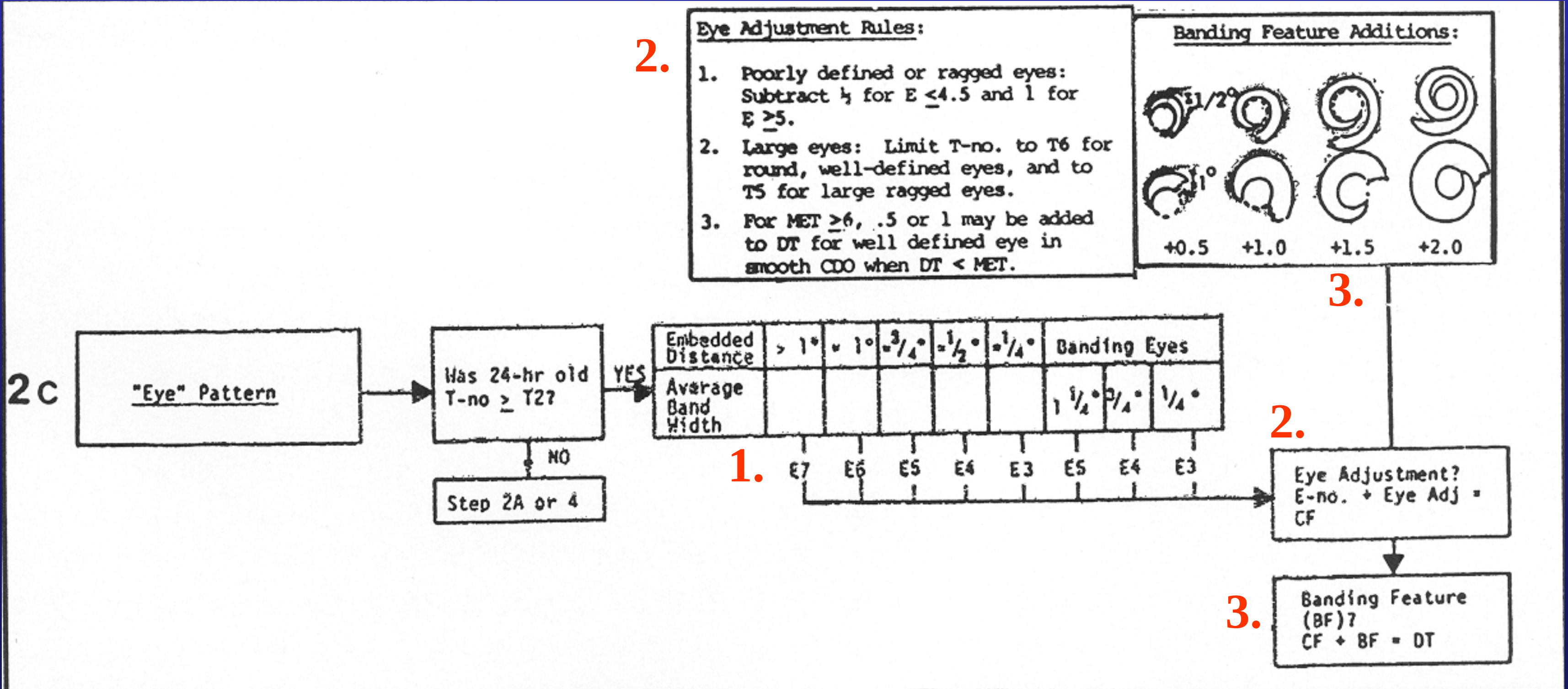


Step 2C - Visible Eye Patterns

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)



2.

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:

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

Step 2C - Eye Patterns

Visible Technique

Is the 24-h 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!

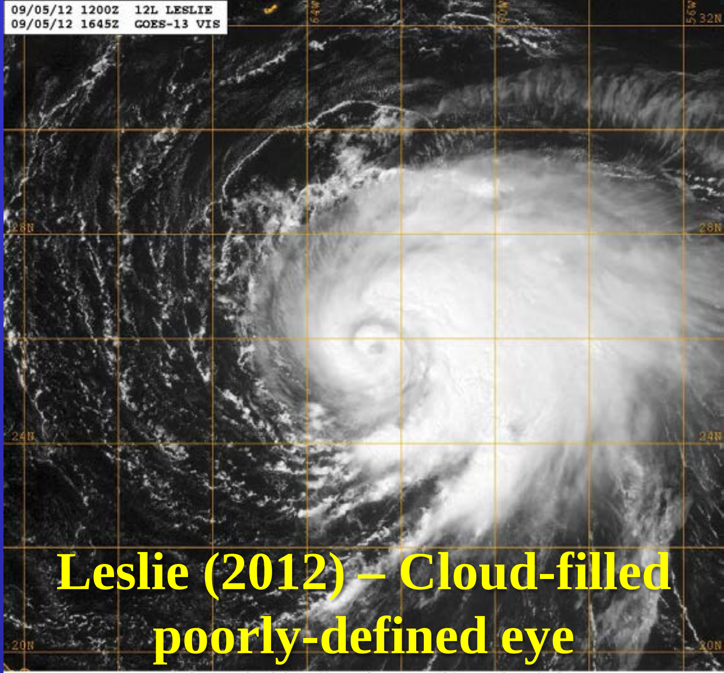
Step 2C - Visible Eye Adjustment

VIS Eye Adjustment Rules:

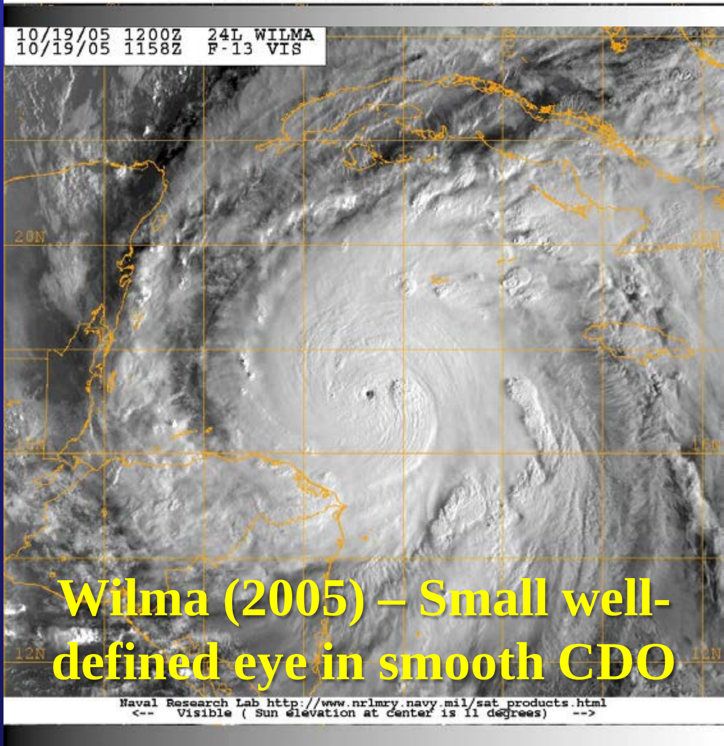
1) Poorly defined or ragged eyes: subtract 0.5 for E≤4.5 and 1 for E≥5.

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.

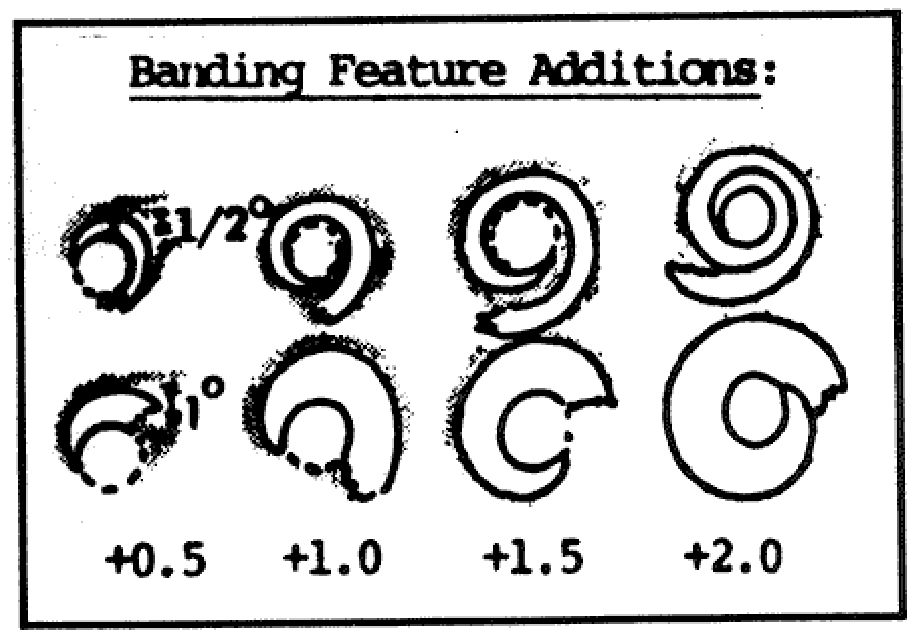


Leslie (2012) – Cloud-filled poorly-defined eye



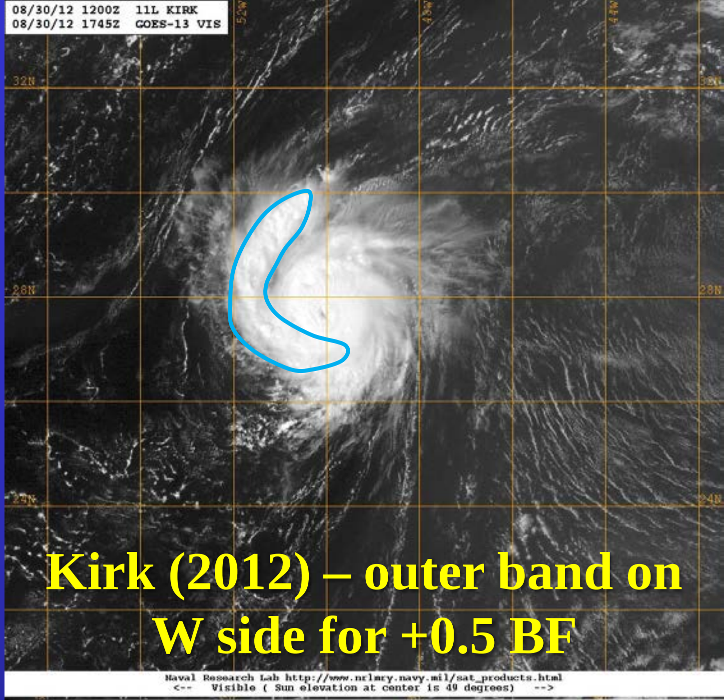
Wilma (2005) – Small well-defined eye in smooth CDO

Step 2C - Visible Outer Banding

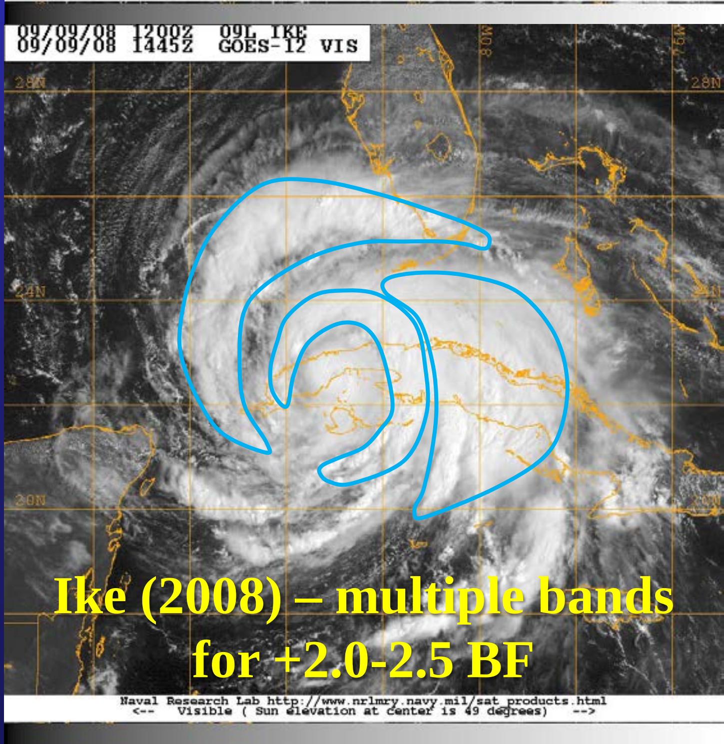


Banding Feature (BF) Numbers: Match the banding outside of the central convection to that shown in the pictograph.

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



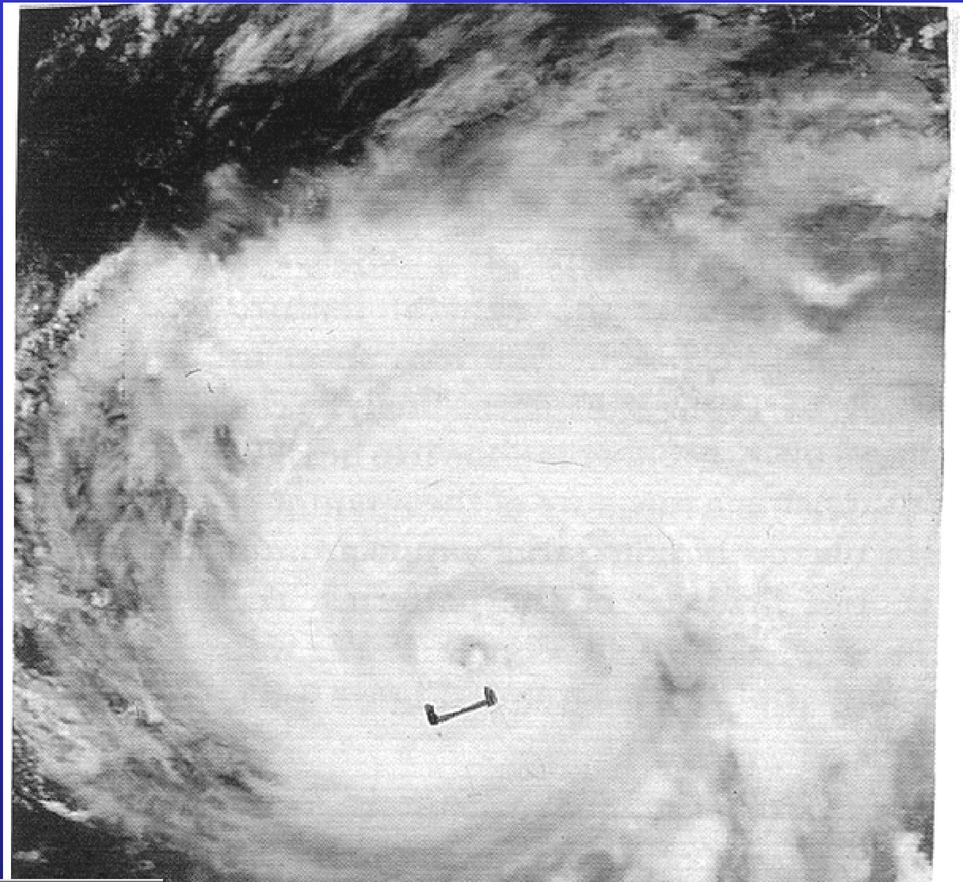
Kirk (2012) – outer band on W side for +0.5 BF

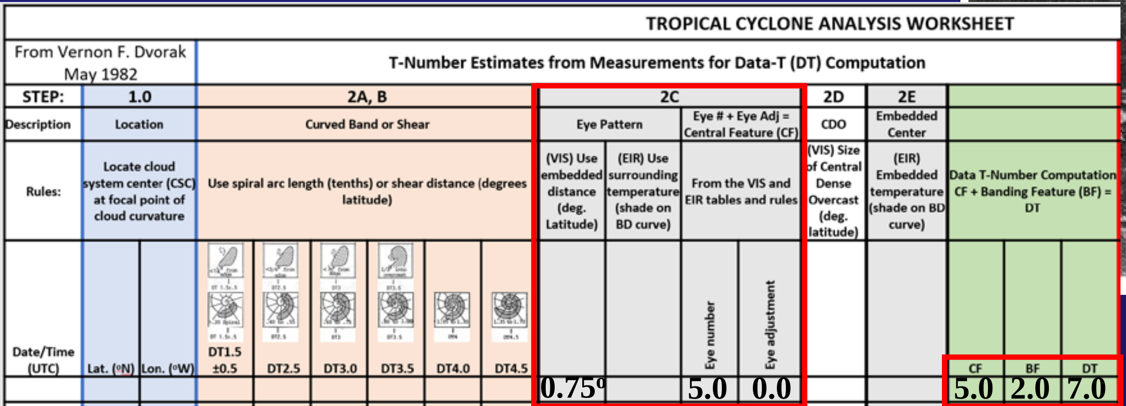


Ike (2008) – multiple bands for +2.0-2.5 BF

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

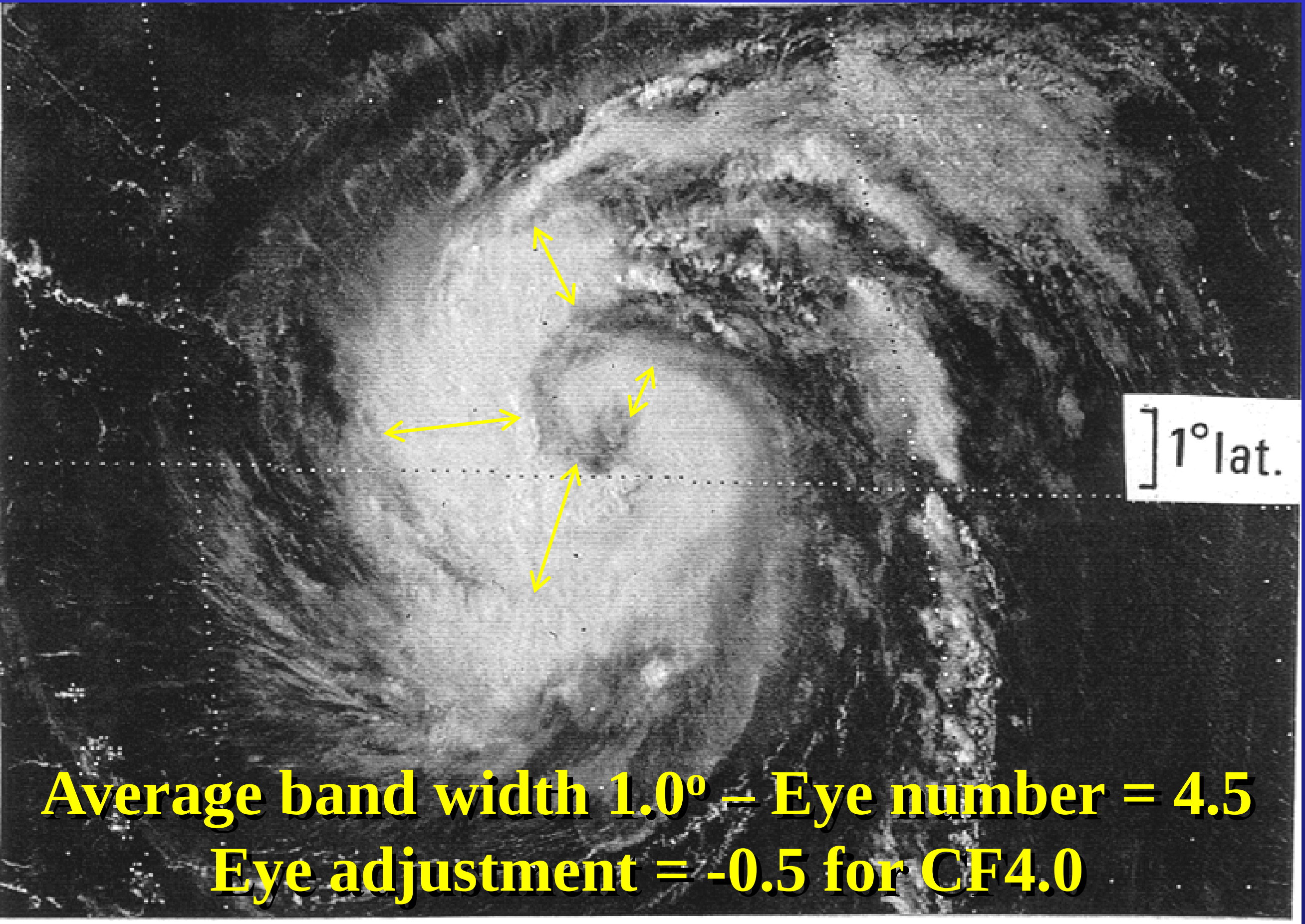




TROPICAL CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
									0.75º		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 is determined by the <u>average</u> width of the band surrounding the eye.

The pattern uses the eye adjustment rules.

It is only used with <u>visible</u> imagery.

From Vernon F. Dvorak May 1982			T-Number Estimates from Measurements for Data-T (DT) Computation														
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (°N)	Lon. (°W)	 DT1.5 ±0.5	 DT2.5	 DT3.0	 DT3.5	 DT4.0	 DT4.5			Eye number	Eye adjustment			CF	BF	DT
									1.0^{o}		4.5	-0.5			4.0	0.0	4.0

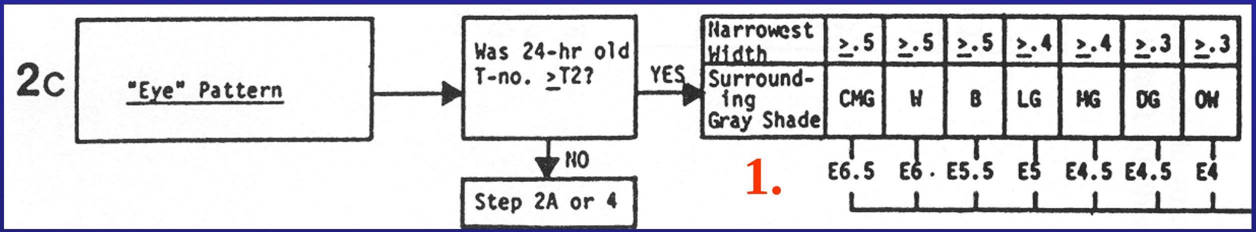
Can also used a curved band with 1.2-1.3 banding for a DT=4.0+

Step 2C - Infrared Eye Patterns

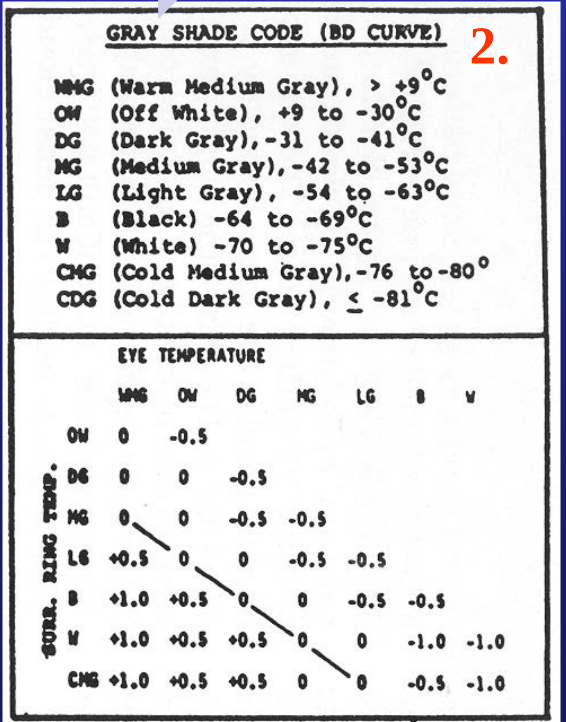
1. Find the coldest color on the BD enhancement that <u>completely surrounds</u> the eye with a thickness greater than the <u>specified width</u> (closed ring surrounding the eye)

2. Make eye adjustment based on the color on the <u>warmest</u> 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)



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

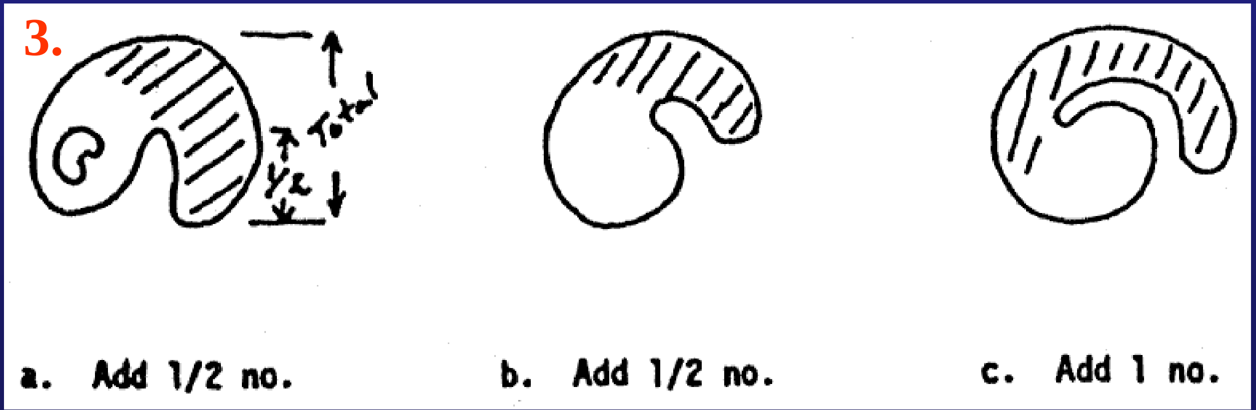


GRAY SHADE CODE (BD CURVE) 2.

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



Step 2C - Eye Patterns

Infrared Technique

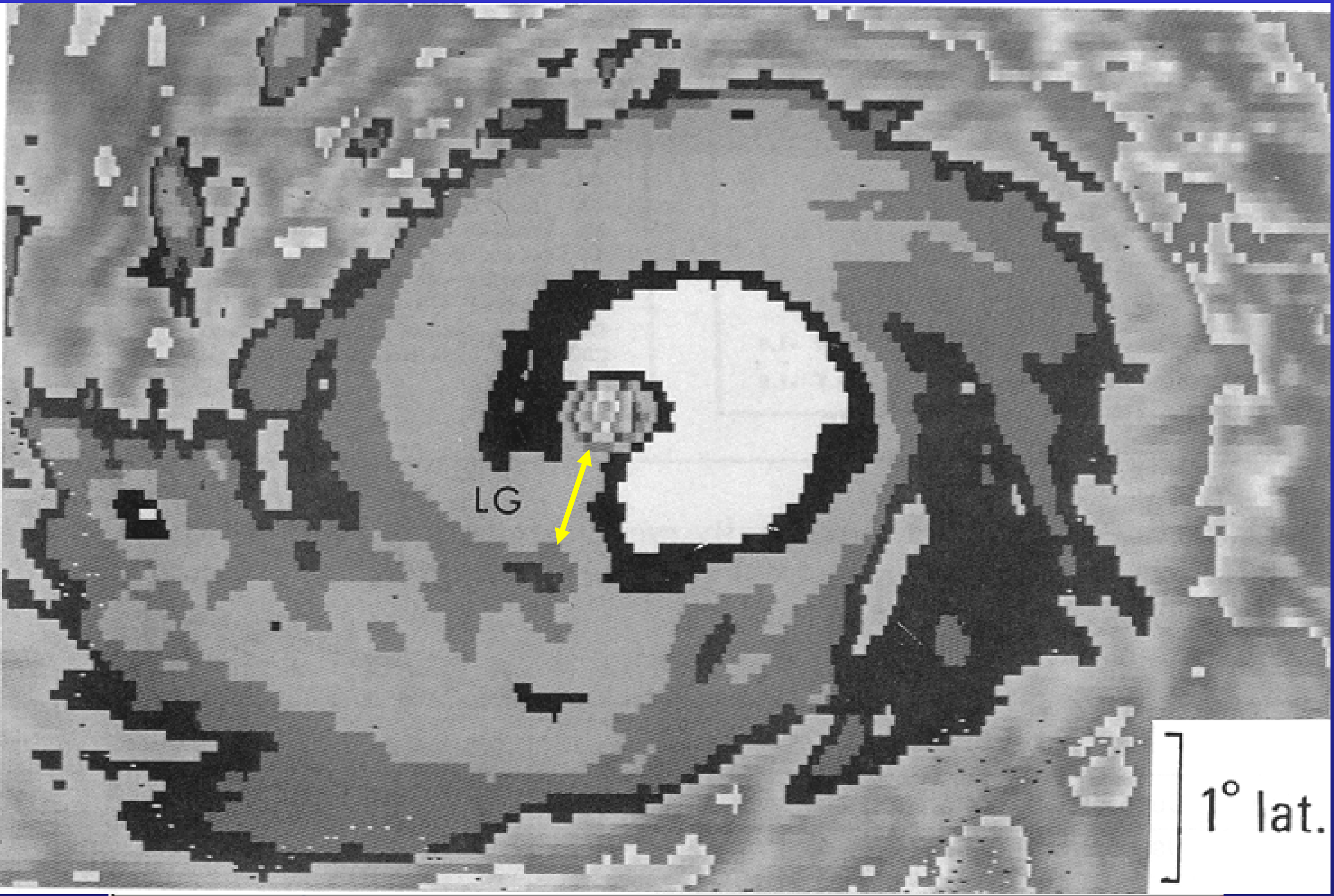
Is the 24-h old FT > 2.0? If not, go to step 2A or step 4.

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

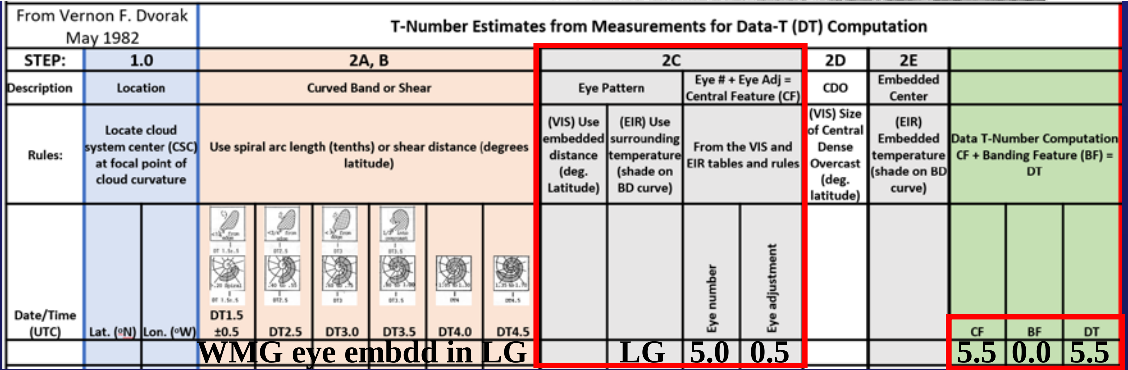
Eye Adjustment:

	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

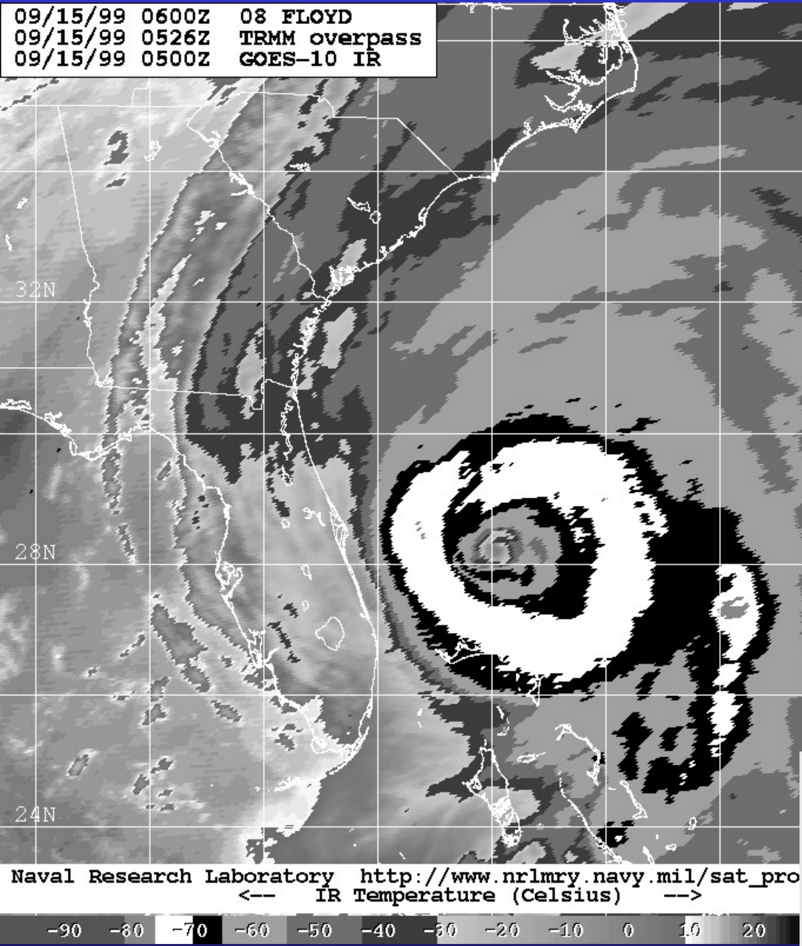


Light Gray (LG) is the coldest color surrounding the eye that meets the width criteria. The eye temperature is Warm Mediun Gray (WMG). The Eye number is 5.0, while the Eye adjustment is +0.5 - CF=5.5



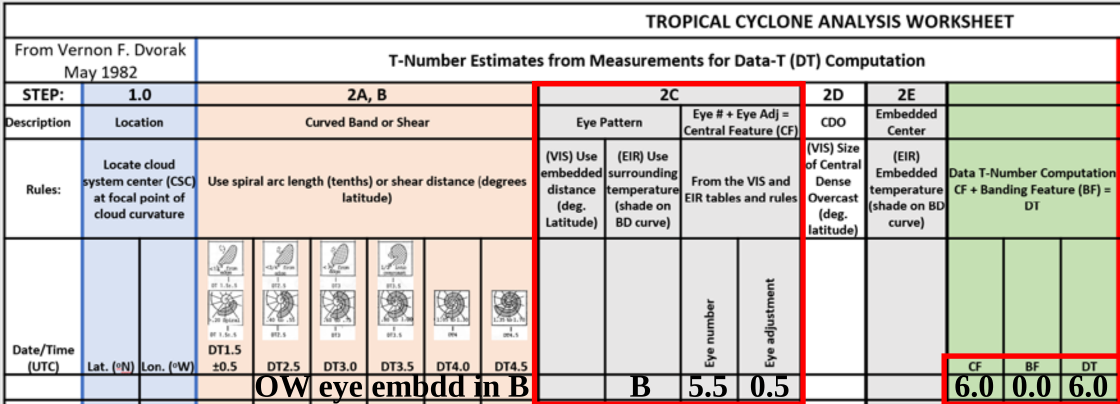
From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			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!

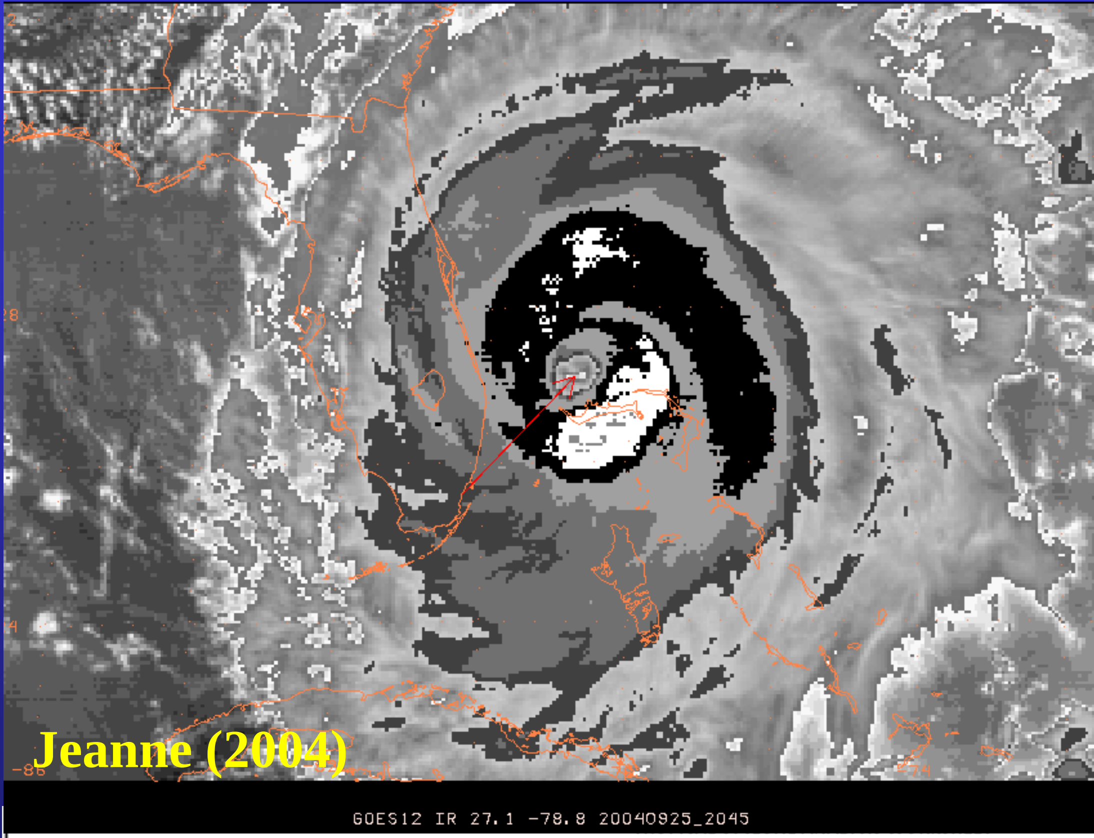


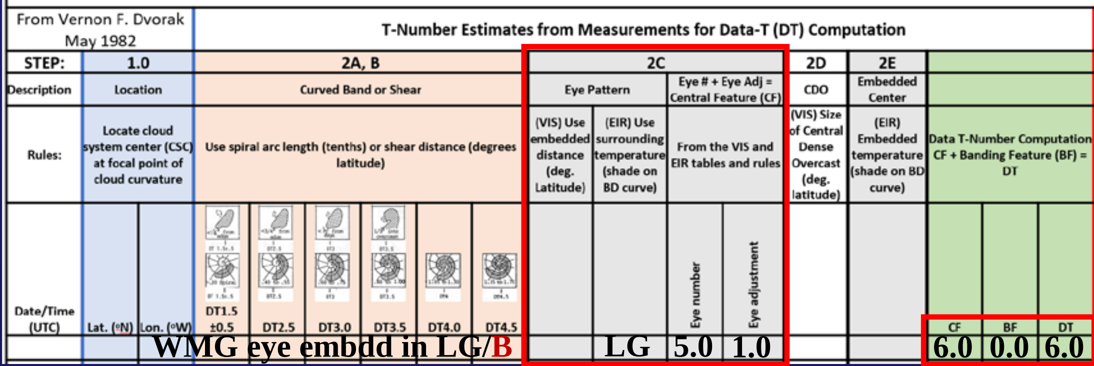
TROPICAL CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			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 <u>Eye Adjustment</u> Can Differ From Color Used For <u>Eye Number</u>

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 <u>eye number</u> uses Light Gray (LG) for a 5.0, while the <u>eye adjustment</u> is determined by a Warm Medium Gray (WMG) embedded in B (+1.0) - CF=6.0


Jeanne (2004)



From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
			WMG eye embdd in LG/B							LG	5.0	1.0			6.0	0.0	6.0

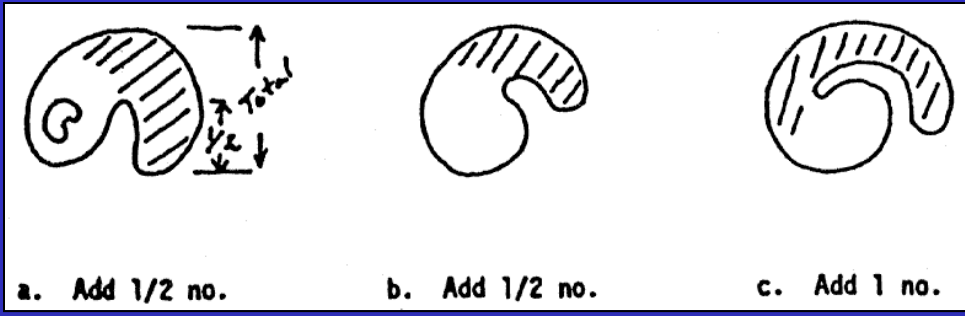
Step 2C - Infrared banding

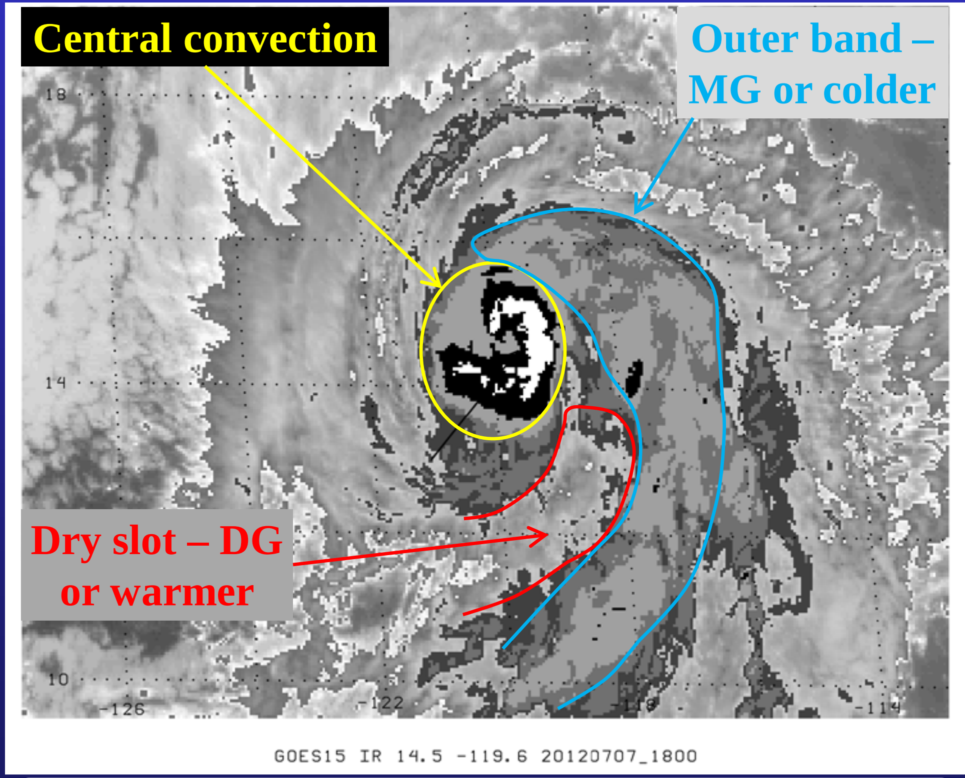
Differs *significantly* from visible banding

Used <u>only</u> when the CF/DT without banding is less than MET

Used <u>only</u> for cloud patterns of CF=4 or more

Band must be MG or colder while dry slot must be DG or warmer




Central convection

Outer band – MG or colder

Dry slot – DG or warmer

Daniel (2012) – A potentially eligible IR outer band

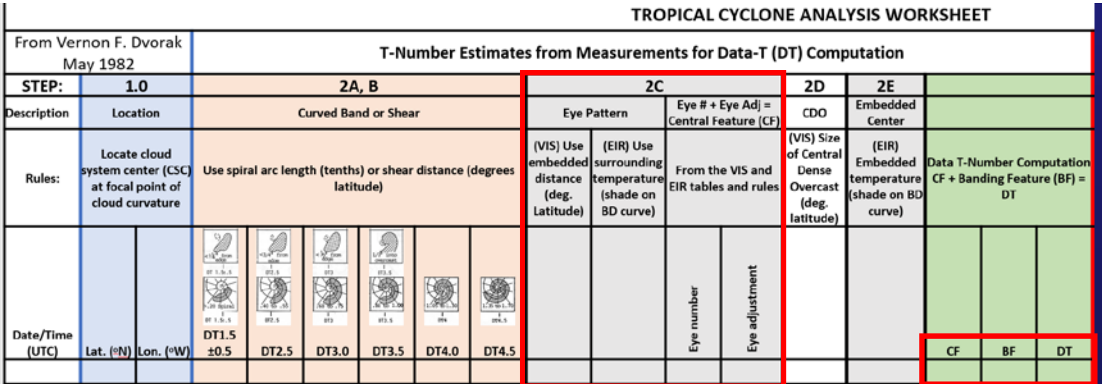
Notes on Step 2C

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

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT

Problem: Satellite Zenith/Viewing Angle and Cloud Tops

The satellite zenith/viewing angle of a TC can impact the Dvorak analysis.

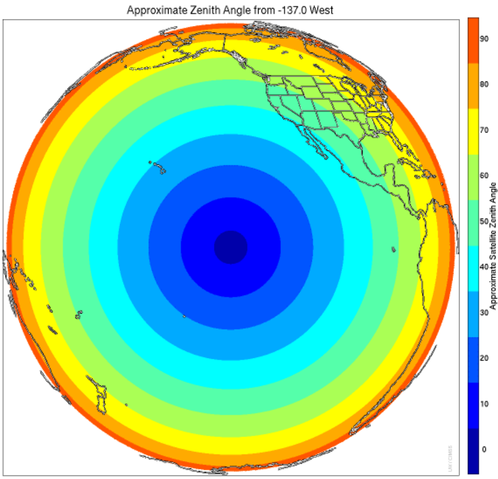
TCs close to the satellite have low zenith/ viewing angles and thus are less of a problem.

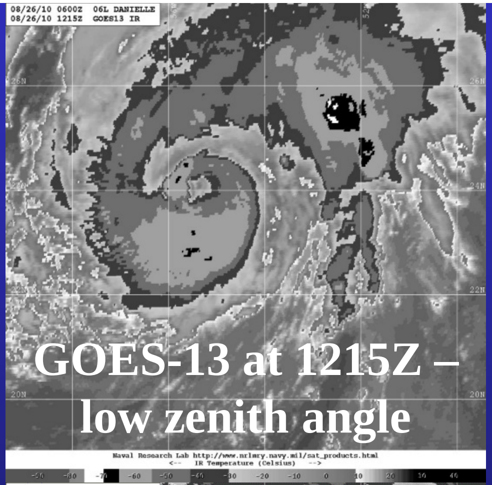
TCs far from the satellite (e. g. near the edge of a full disk scan) are a problem for IR analysis, as IR cloud top temperatures appear too cold.

High zenith/viewing angles can also make it difficult to see to the bottom of the eye.

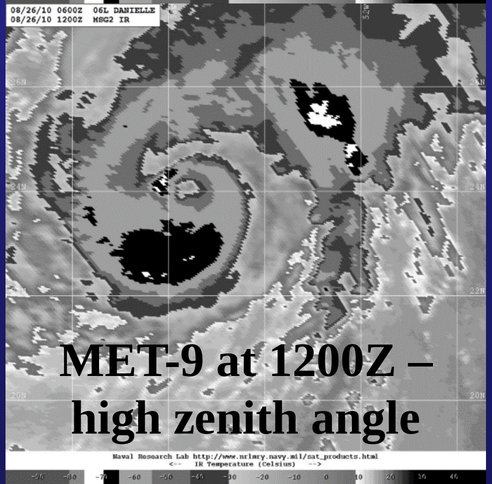
Use the satellite closest to the TC for a Dvorak analysis if at all possible, and use IR DT numbers made at high zenith/viewing angles with caution.

METEOSAT-11 is at 0W, GOES-East at 75W, and GOES-West at 137.5W.





GOES-13 at 1215Z – low zenith angle

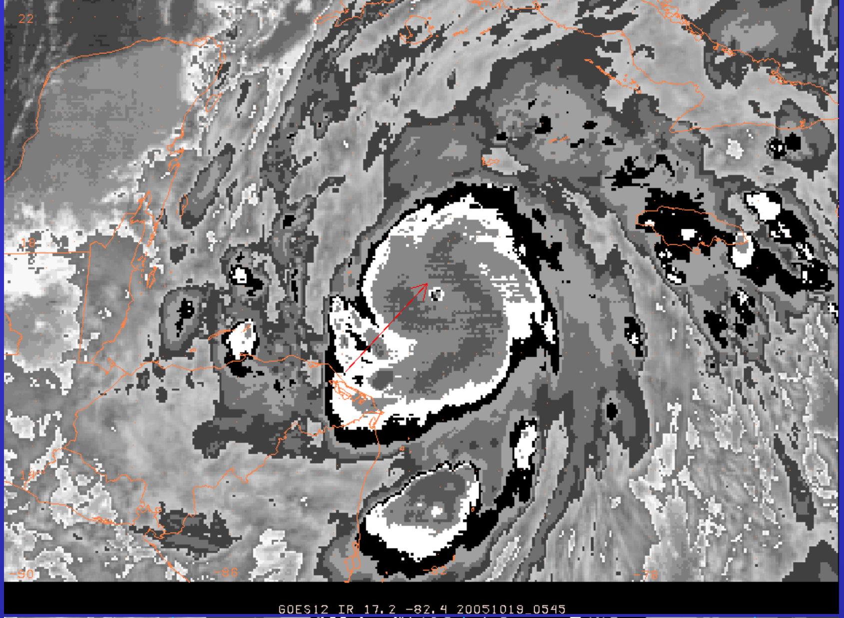


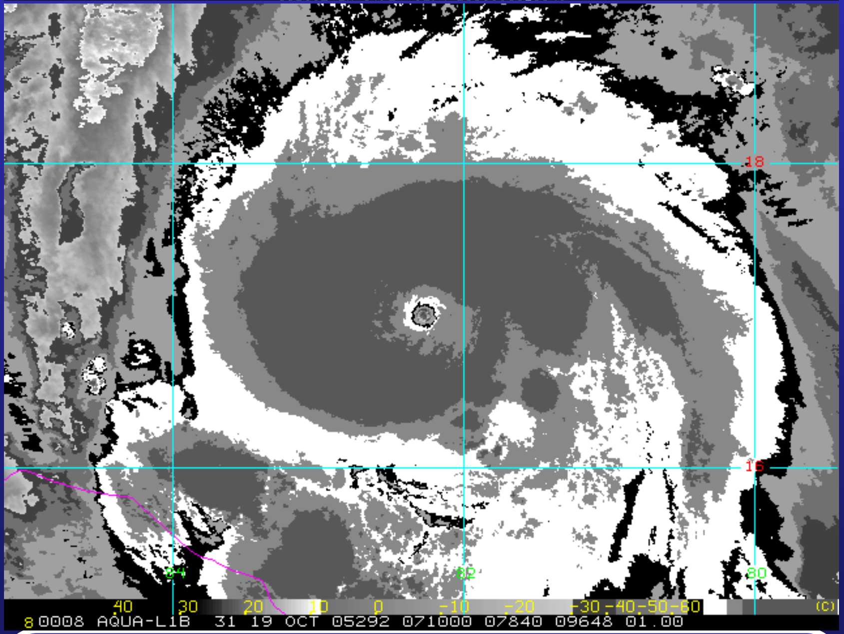
MET-9 at 1200Z – high zenith angle

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.

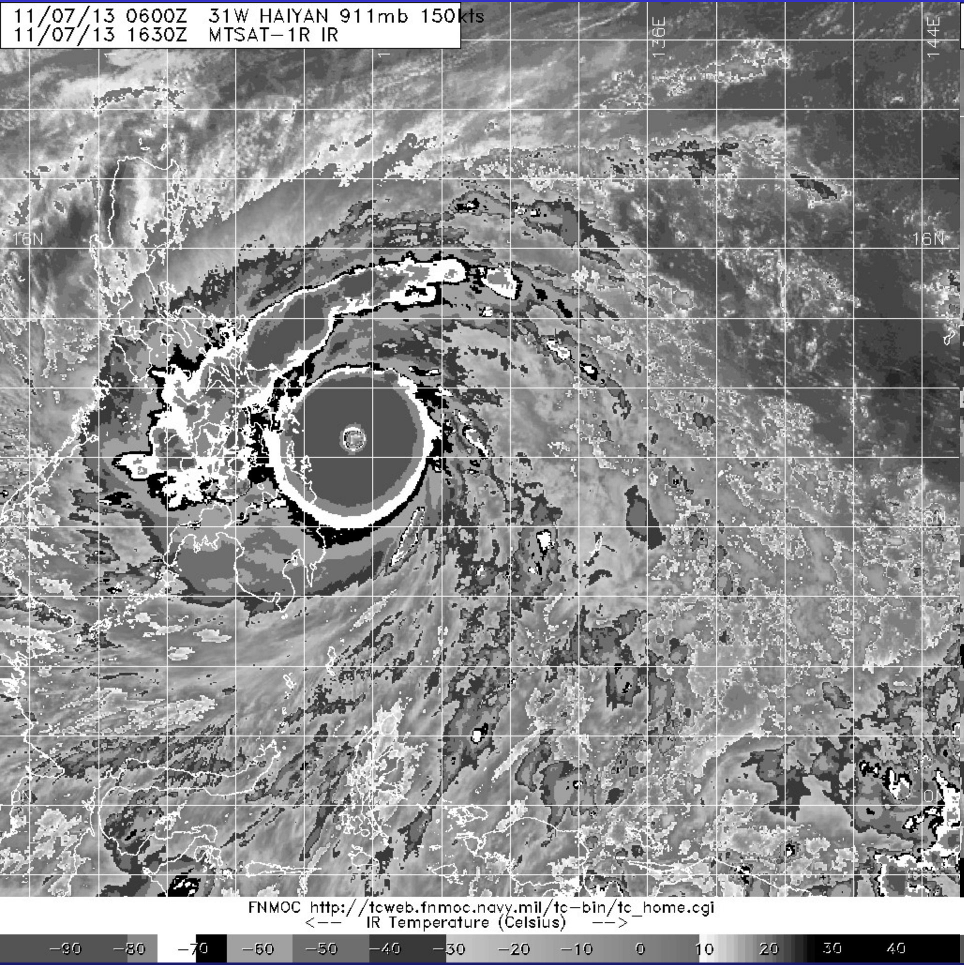
High zenith/viewing angles also make it difficult to see to the bottom of the eye even when they are larger than 10 n mi wide.





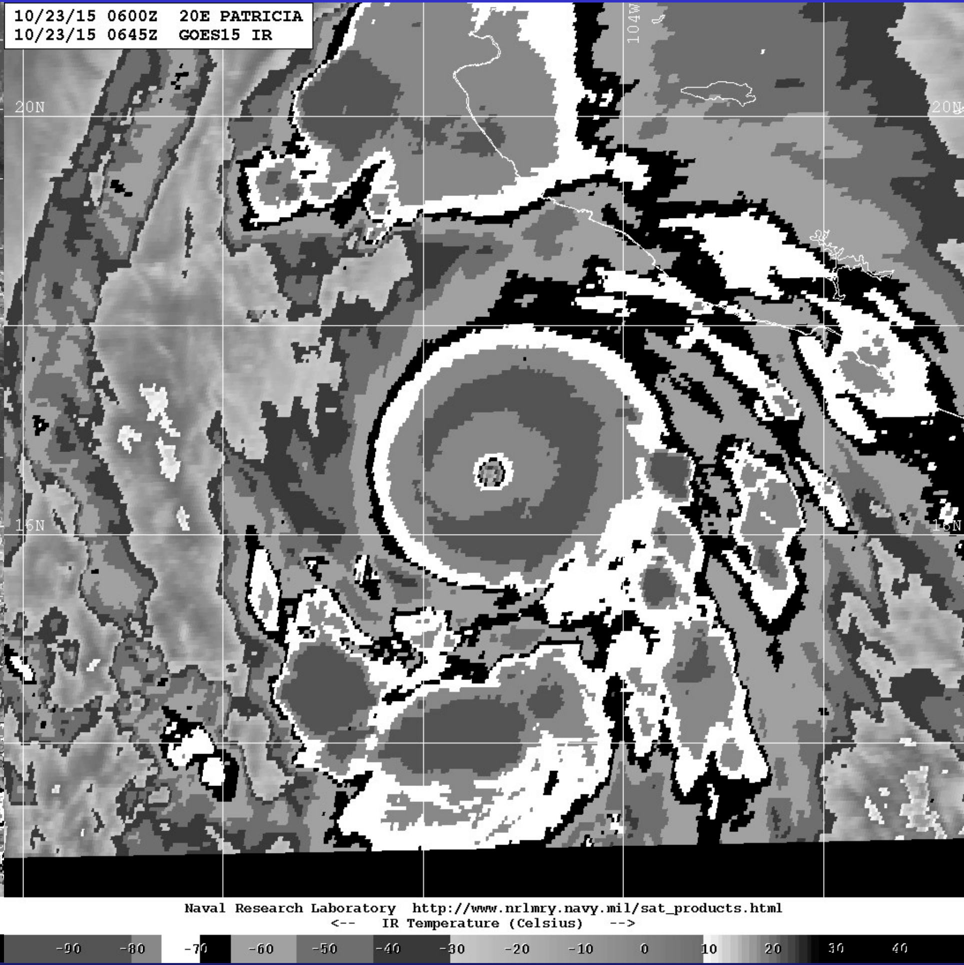
Wilma 2005 - Eye diameter 4 n mi
GOES Eye temperature ~ 0C
NOAA/Aqua Eye temperature ~ +20C

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

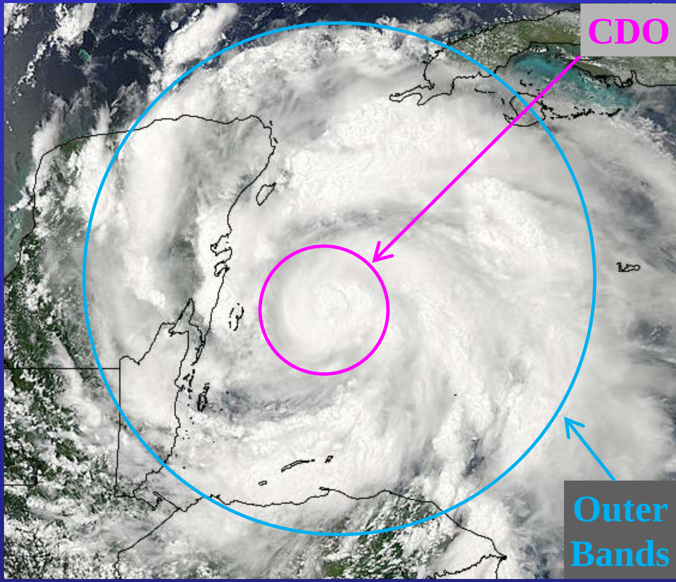
Patterns are complimentary - CDO uses VIS imagery and Embedded Center uses IR.

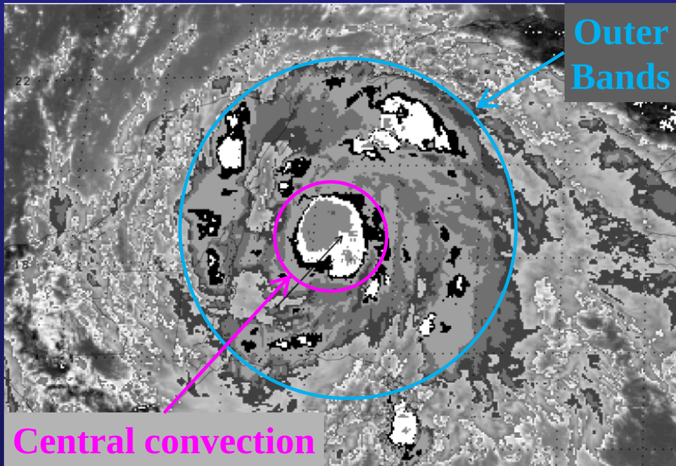
Both patterns directly produce CF numbers.

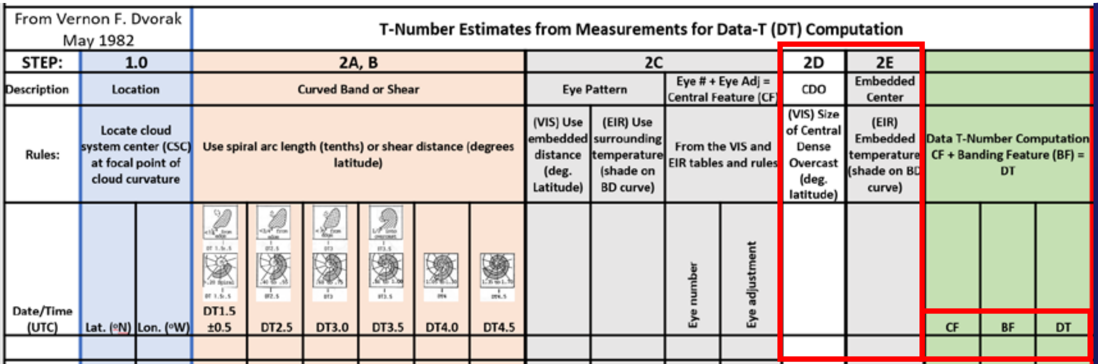
CDO pattern measures the size of the CDO.

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.







From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT

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

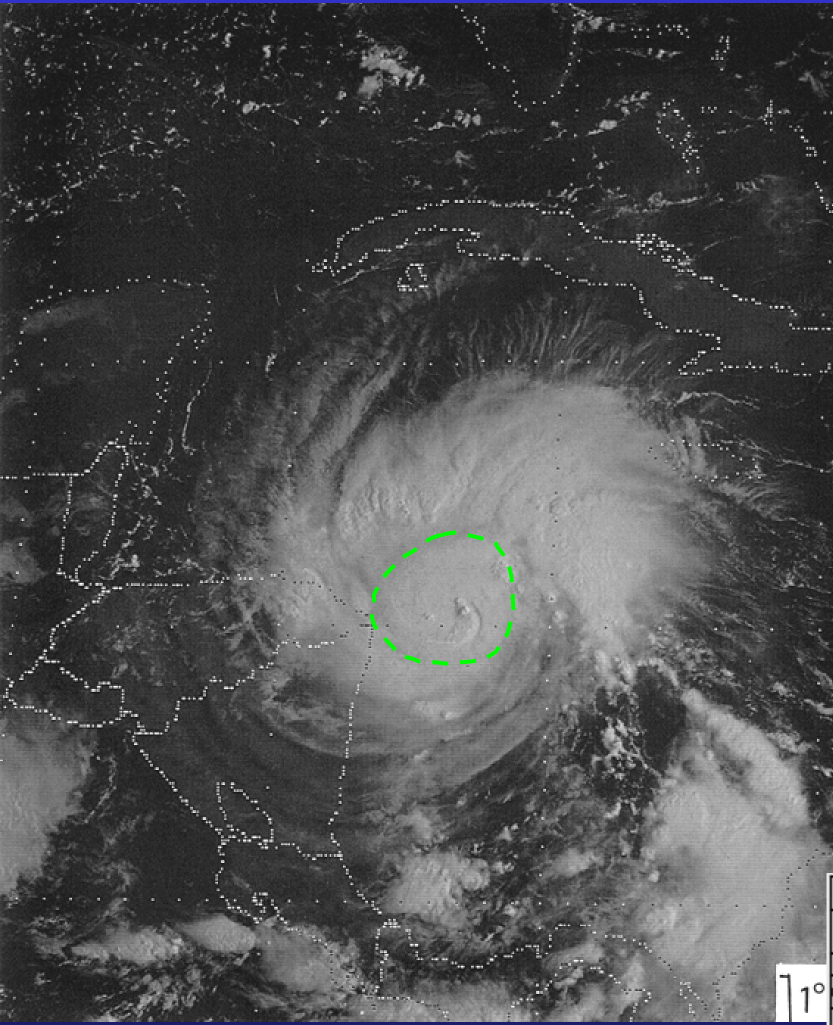
Step 2D - Is the CDO ≥ 0.75 deg wide? If not, go to step 2A or step 4.

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

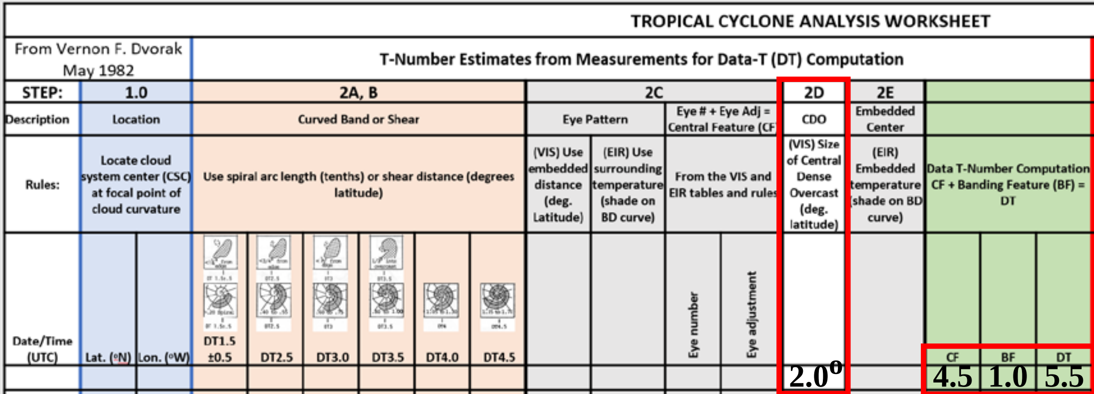
Step 2E - Is the 12 hour old FT ≥ 3.5? If not, go to step 2A or step 4.

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



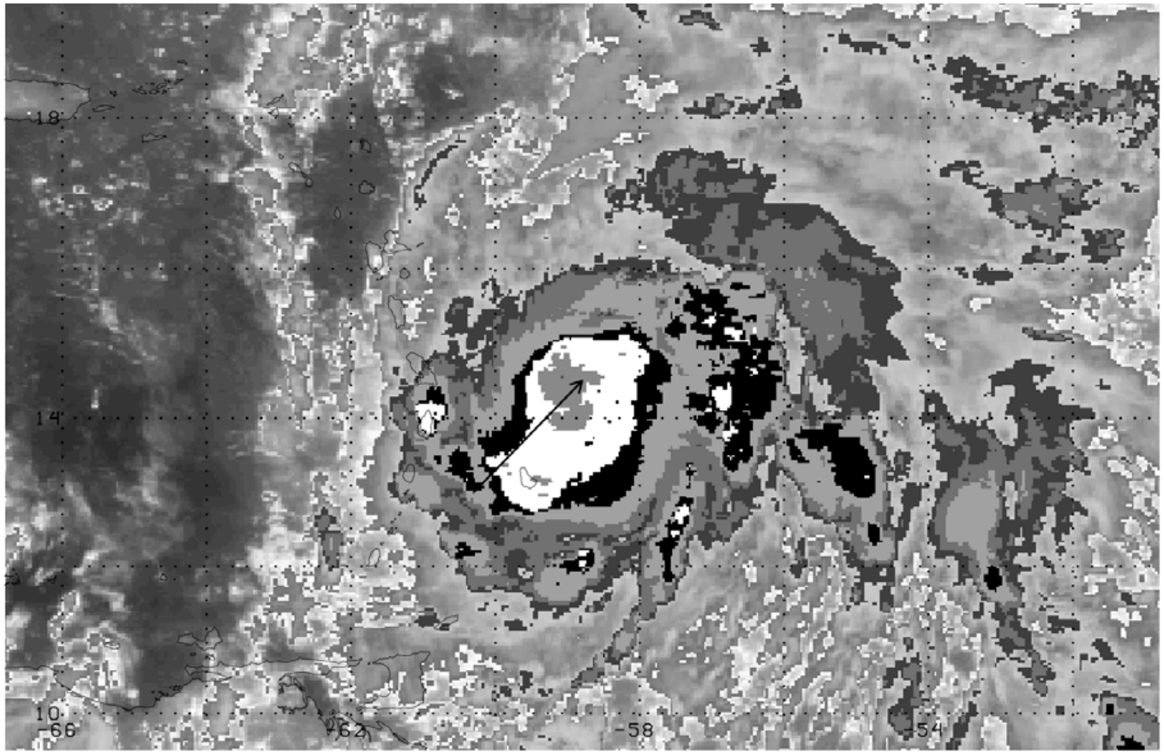
The CDO is about 2 deg wide – CF=4.5 + 1.0 for banding around the CDO → DT=5.5



TROPICAL CYCLONE ANALYSIS WORKSHEET

From Vernon F. Dvorak May 1982	T-Number Estimates from Measurements for Data-T (DT) Computation																
STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
													2.0°		4.5	1.0	5.5

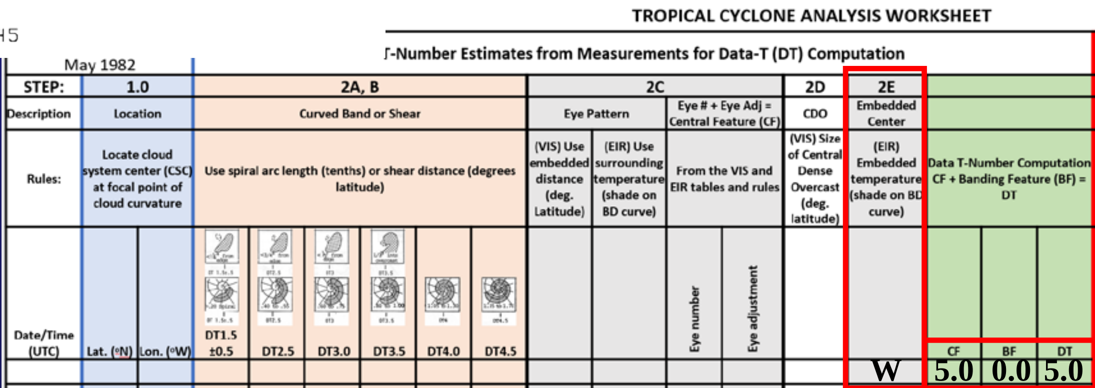
Step 2E - Measuring an Embedded Center



GOES-E IR 14.5 -58.8 20170918_0545

Maria (2017)

CSC embedded in W - DT=5.0



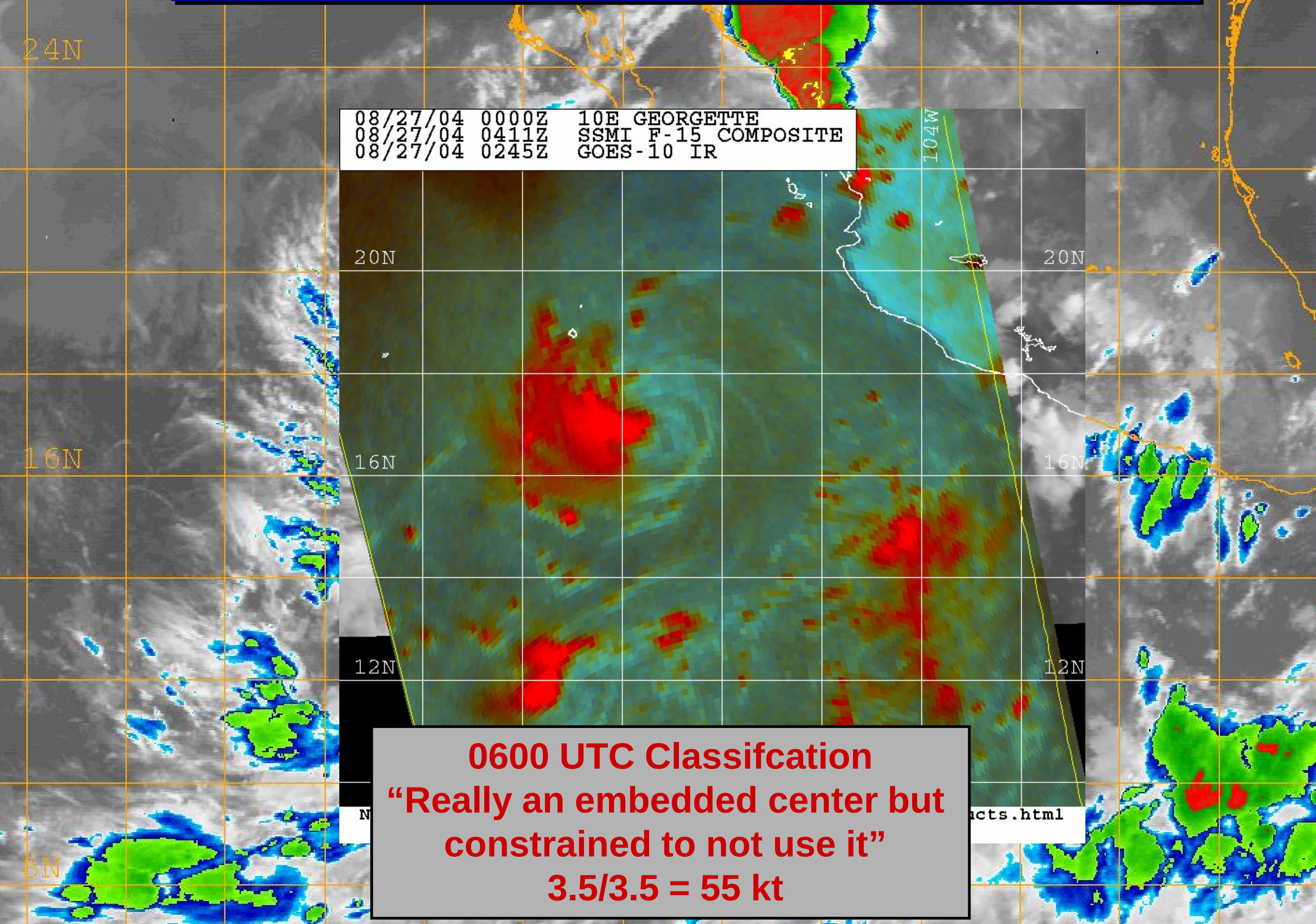
TROPICAL CYCLONE ANALYSIS WORKSHEET

May 1982

T-Number Estimates from Measurements for Data-T (DT) Computation

STEP:	1.0		2A, B						2C				2D	2E			
Description	Location		Curved Band or Shear						Eye Pattern		Eye # + Eye Adj = Central Feature (CF)		CDO	Embedded Center			
Rules:	Locate cloud system center (CSC) at focal point of cloud curvature		Use spiral arc length (tenths) or shear distance (degrees latitude)						(VIS) Use embedded distance (deg. Latitude)	(EIR) Use surrounding temperature (shade on BD curve)	From the VIS and EIR tables and rules		(VIS) Size of Central Dense Overcast (deg. latitude)	(EIR) Embedded temperature (shade on BD curve)	Data T-Number Computation CF + Banding Feature (BF) = DT		
Date/Time (UTC)	Lat. (ºN)	Lon. (ºW)	DT1.5 ±0.5	DT2.5	DT3.0	DT3.5	DT4.0	DT4.5			Eye number	Eye adjustment			CF	BF	DT
														W	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.

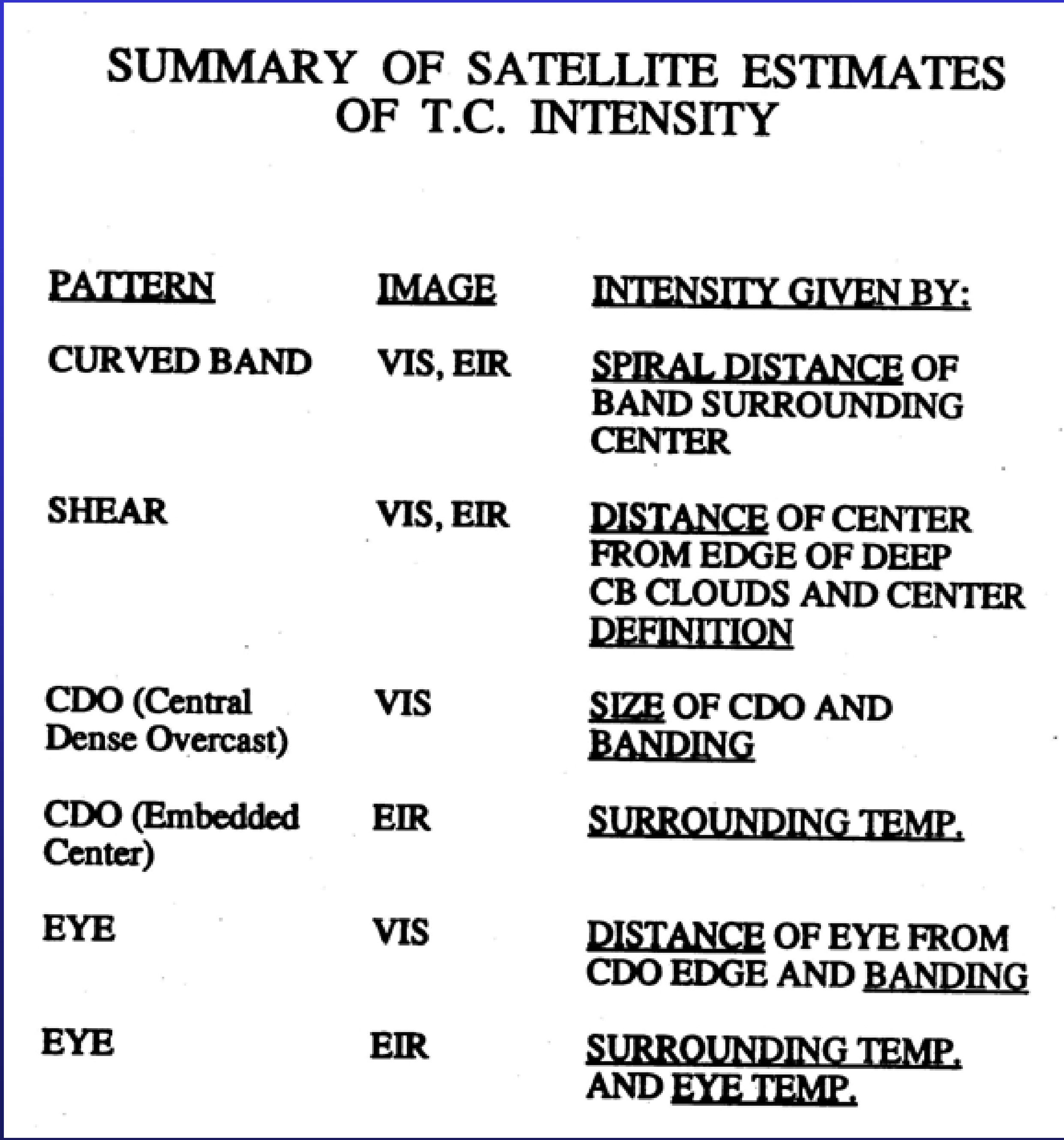
For an elliptical CDO, the CDO size is the average of the sizes of the long and short axes of the ellipse.

Embedded Center pattern can only be used when the 12-h old FT is 3.5 or greater as otherwise it can produce unrealistically high intensity estimates.

Embedded Center pattern is an uncertain Dvorak measurement - where the classifier puts the CSC makes a significant difference in the intensity estimate.

When available and appropriate, use of VIS CDO is preferable to use of IR embedded center.

To summarize the cloud pattern types...



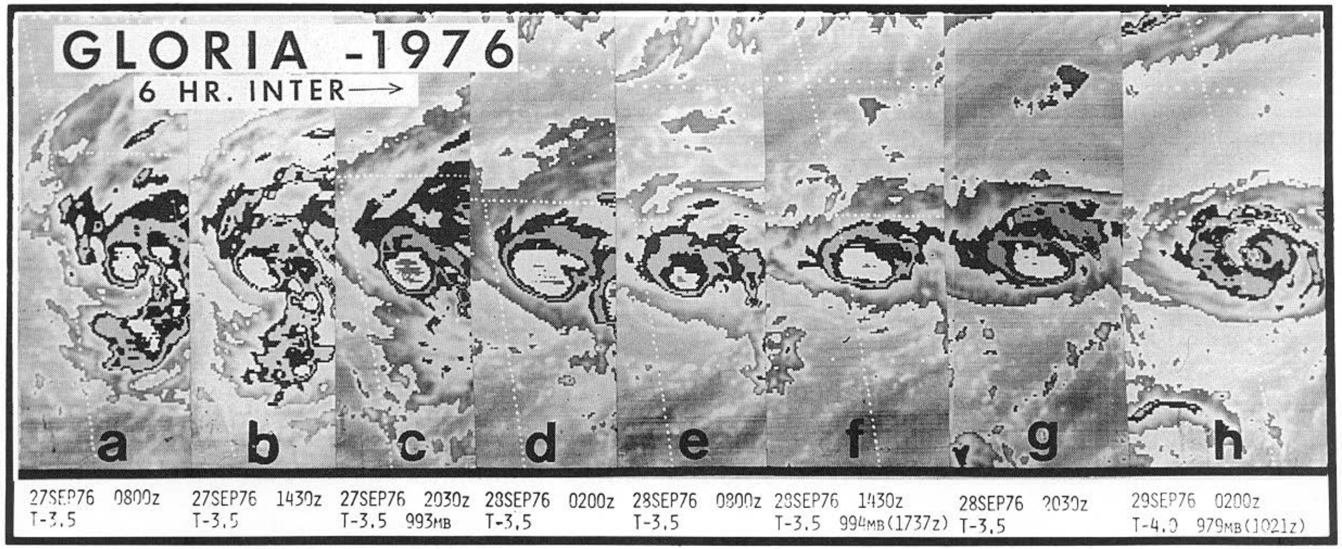
SUMMARY OF SATELLITE ESTIMATES OF T.C. INTENSITY

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.

Step 3 - Central Cold Cover Pattern

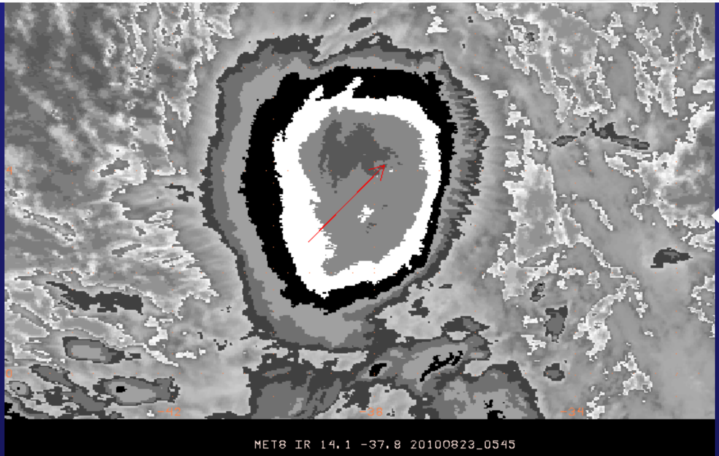
Central Cold (Dense) Cover Pattern

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



It is also known as "bursting" pattern.

It can resemble shear or CDO/embedded center patterns.



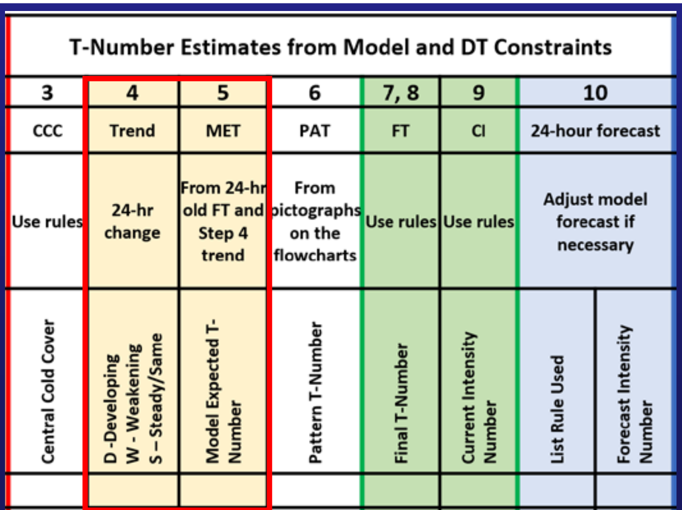
Danielle (2010) – a likely CCC pattern

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

The Dvorak Technique employs a conceptual model of TC growth and decay rates over 24-h periods to help filter the diurnal convective variations observed in TC cloud patterns.

For trend purposes, always use 24-h comparisons even though intensity estimate are made more frequently (e. g. every 6 h).

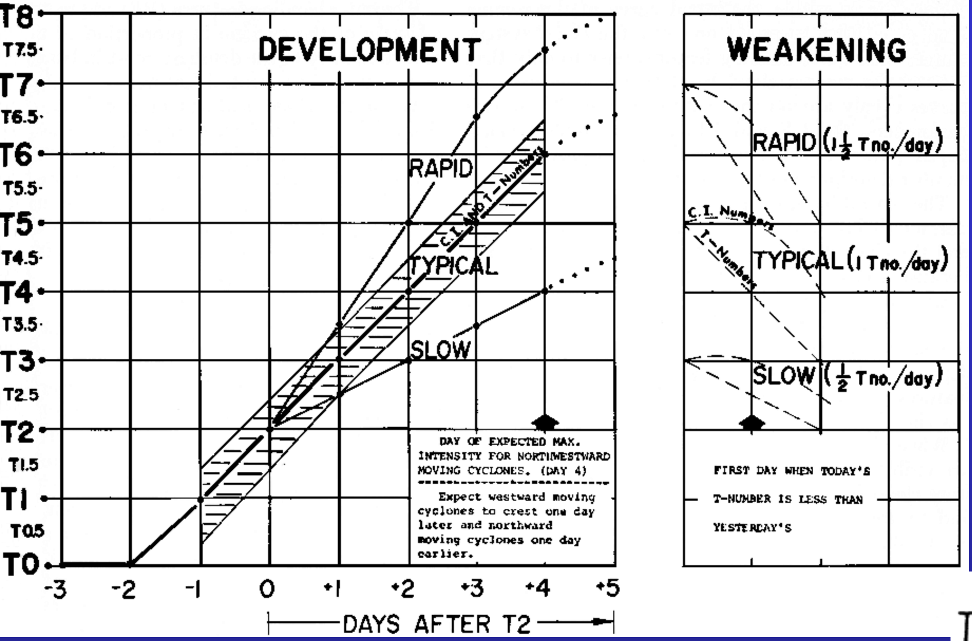
24-h trends are reported as Developing, Weakening, or Steady.



T-Number Estimates from Model and DT Constraints

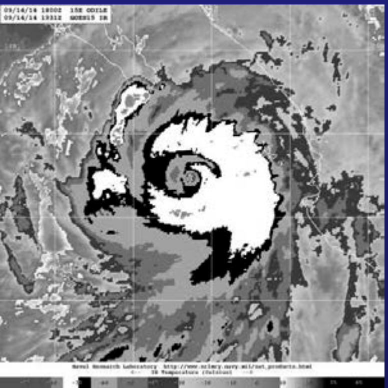
3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number

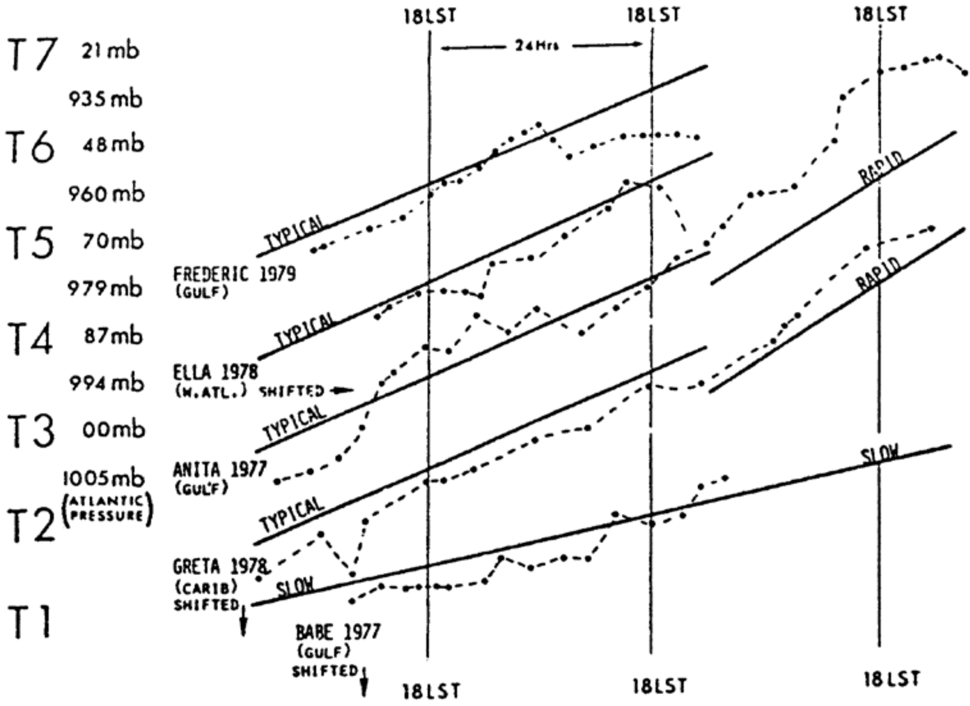
Dvorak Model Development Curves



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 not part of the Dvorak conceptual model.





Step 4 - Determine 24-h Trend

Developing	Weakening	Steady
Increased convection near CSC (larger or colder CDO)	Decreased convection near CSC (smaller or warmer CDO)	No noticeable 24-h 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 h 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	

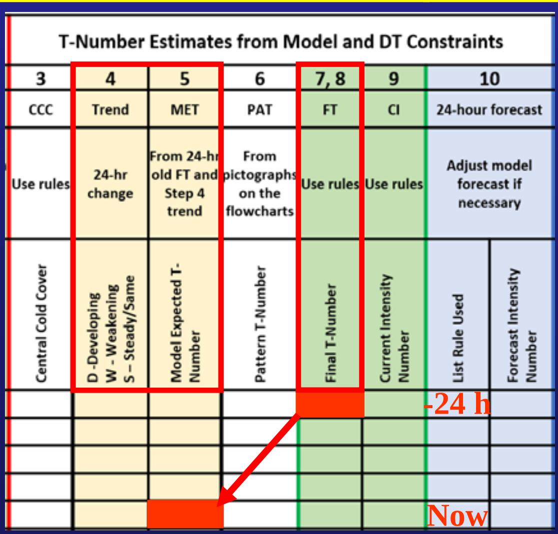
Step 5 - Model Expected T-Number

The MET is a first guess estimate of the intensity based on the 24-hold Final T-Number and the current determined 24-h trend

For a Steady trend, the MET = the 24-h old FT

The MET for the first classification of a system is 1.0.

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



T-Number Estimates from Model and DT Constraints

3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number
						-24 h	
						Now	

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

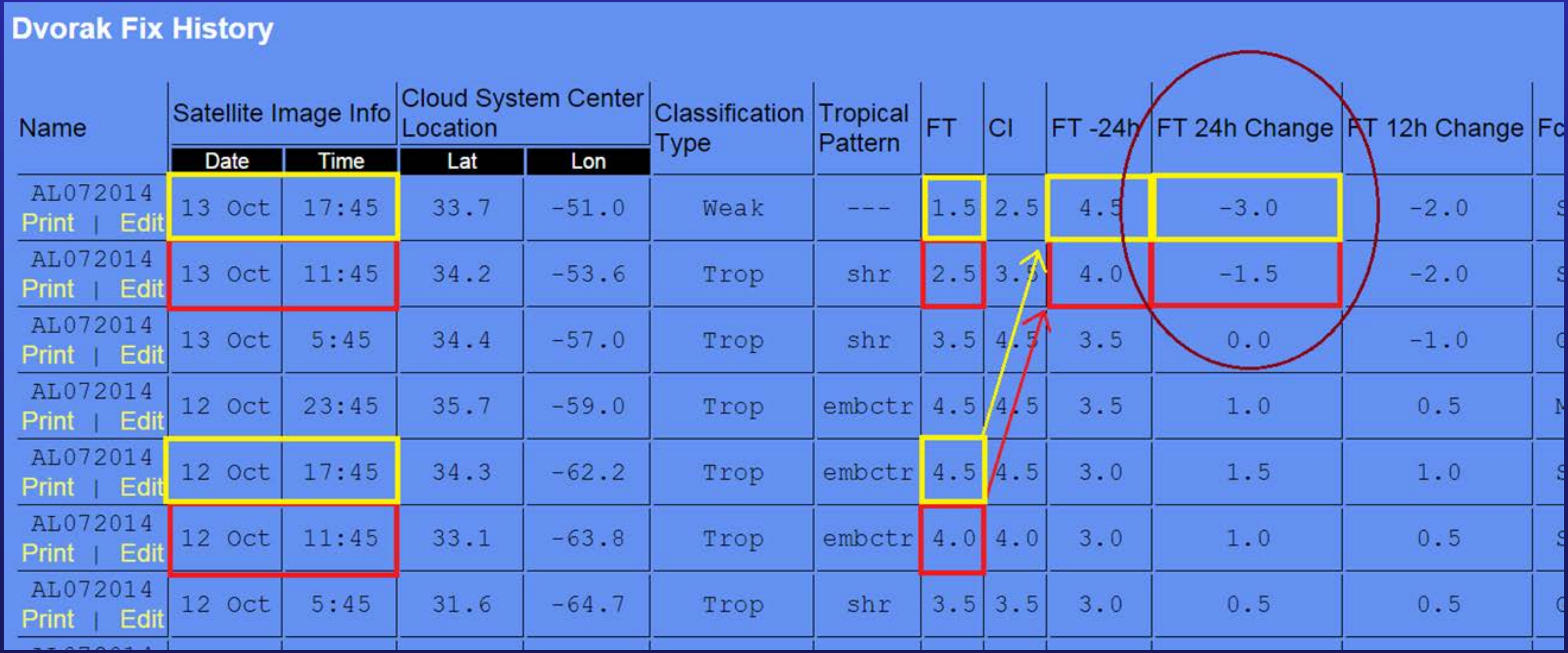
Two consecutive previous Dvorak measurements of rapid or slow development/ weakening are needed to establish rapid or slow 24-h changes

- *Look at the previous two FT values and compare them to the respective FT values from 24 h 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 of rapid development/weakening and signs of strong intensification or weakening (Step 10, rules C and A)

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-h changes in the column labeled “FT 24h Change”. If the 24-h trend for the 00Z /14 Oct fix is weakening, the prior trends justify a W+, since there are two consecutive 24-h 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 Print | Edit	13 Oct	17:45	33.7	-51.0	Weak	---	1.5	2.5	4.5	-3.0	-2.0	S
AL072014 Print | Edit	13 Oct	11:45	34.2	-53.6	Trop	shr	2.5	3.5	4.0	-1.5	-2.0	S
AL072014 Print | Edit	13 Oct	5:45	34.4	-57.0	Trop	shr	3.5	4.5	3.5	0.0	-1.0	C
AL072014 Print | Edit	12 Oct	23:45	35.7	-59.0	Trop	embctr	4.5	4.5	3.5	1.0	0.5	M
AL072014 Print | Edit	12 Oct	17:45	34.3	-62.2	Trop	embctr	4.5	4.5	3.0	1.5	1.0	S
AL072014 Print | Edit	12 Oct	11:45	33.1	-63.8	Trop	embctr	4.0	4.0	3.0	1.0	0.5	S
AL072014 Print | Edit	12 Oct	5:45	31.6	-64.7	Trop	shr	3.5	3.5	3.0	0.5	0.5	C

Notes on steps 4 and 5

The trend for step 4 is determined by examining satellite images 24 h apart.

The trend for the initial classification is always a normal D.

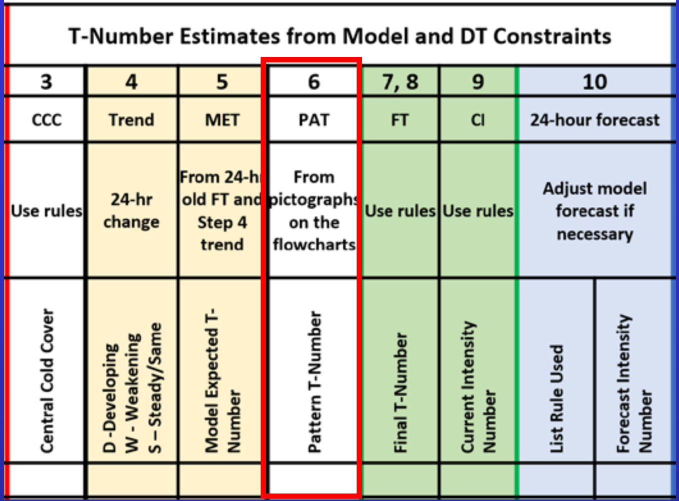
You need at least 24 h of Dvorak classifications to change the development trend. The first 18 h after the initial T1 are always a normal D.

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)

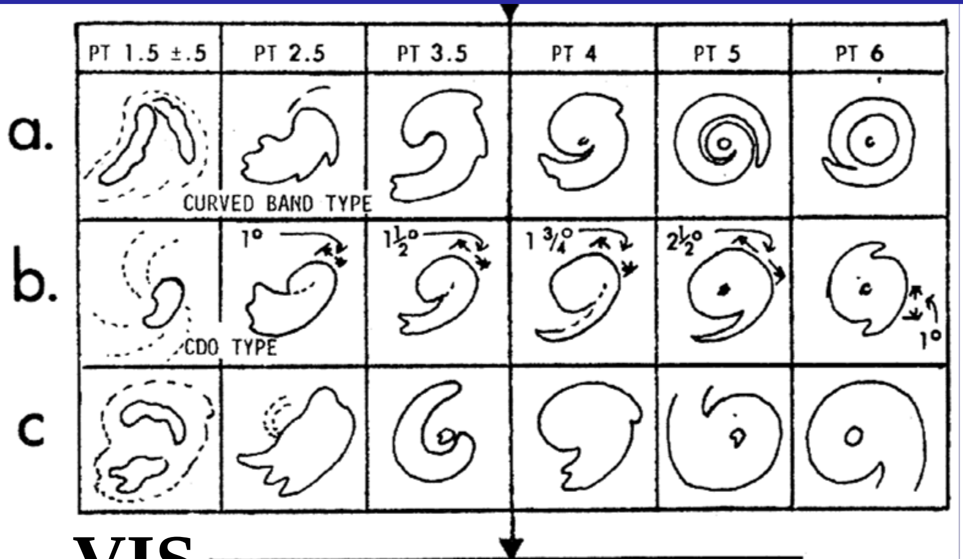
Choose the Pattern T-number by comparing the cyclone cloud pattern to the diagrams on the flow charts

PATs above T6 require extrapolation!



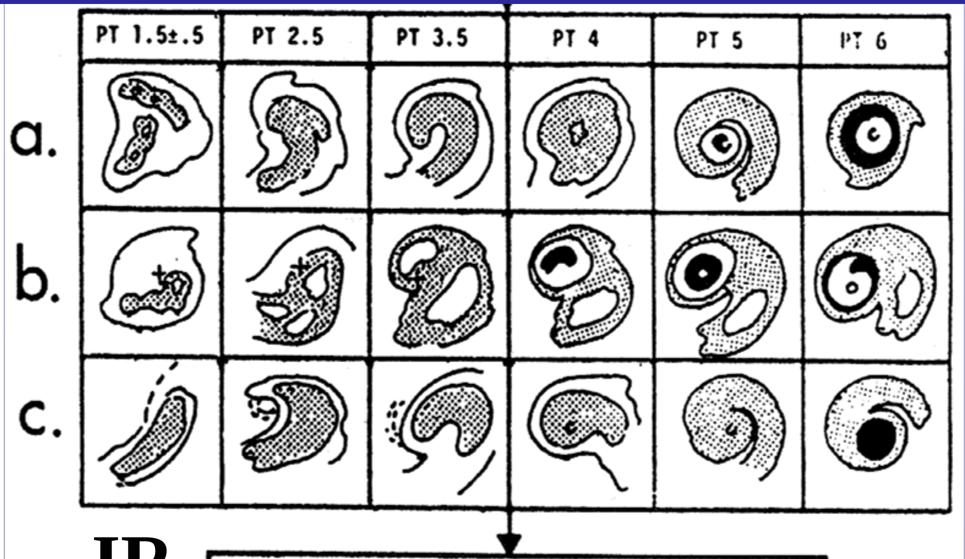
T-Number Estimates from Model and DT Constraints

3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number



VIS

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

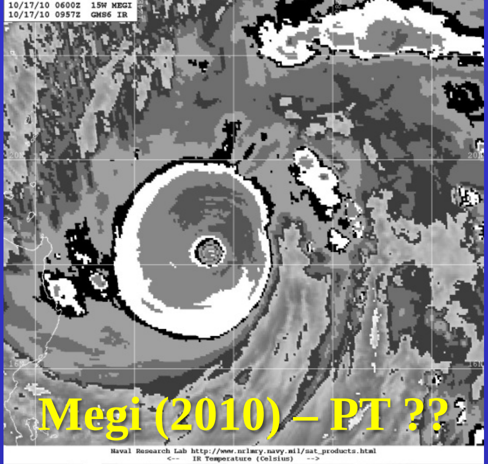


IR

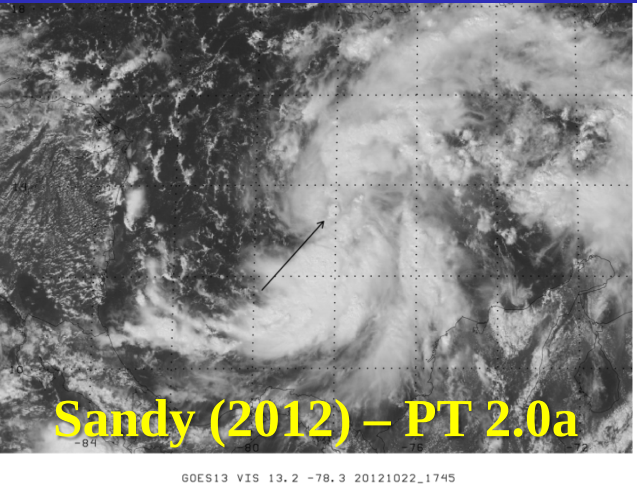
*When hatched part of these patterns is white or colder, add .5 to pattern number.

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

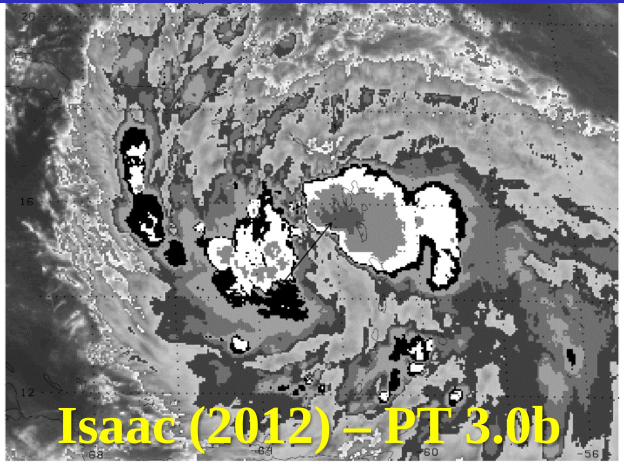
Step 6 - Pattern T-Number (PT or PAT)



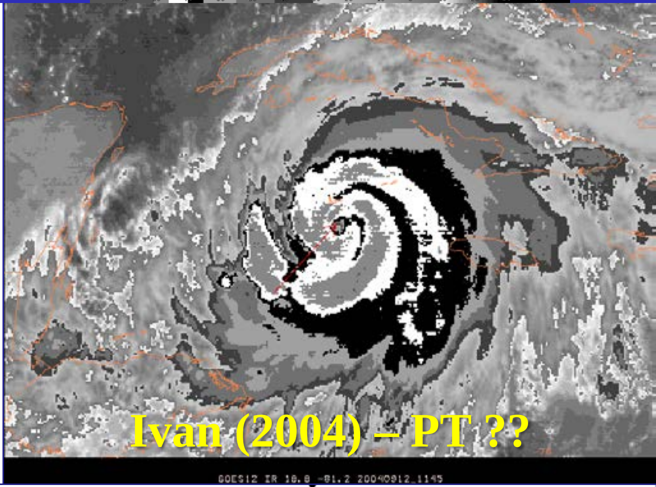
Megi (2010) – PT ??



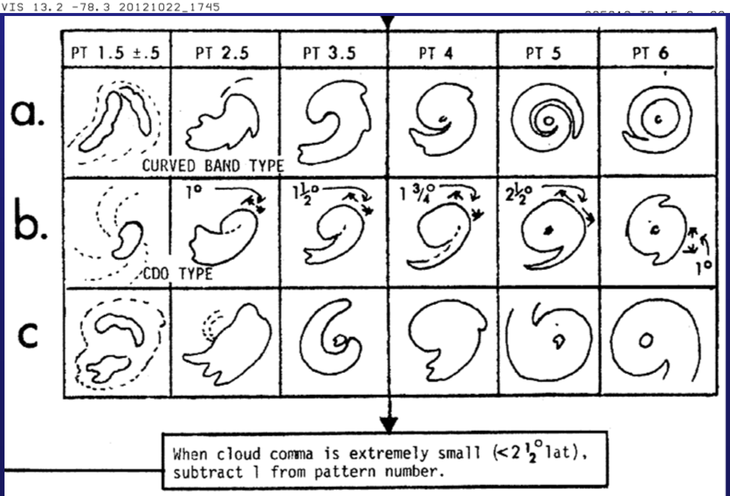
Sandy (2012) – PT 2.0a



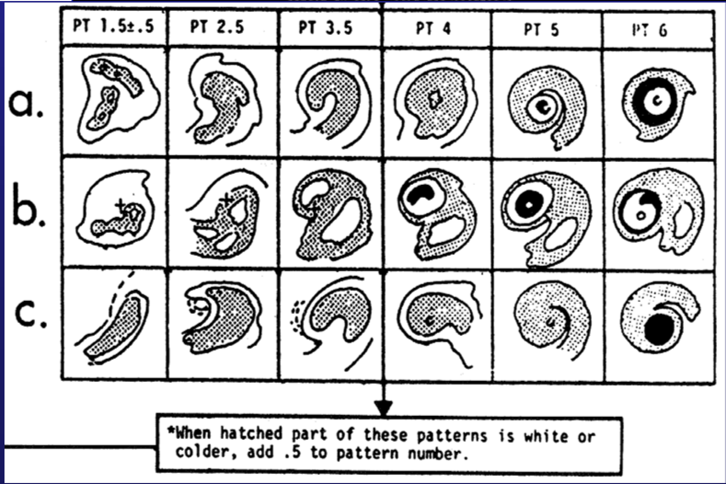
Isaac (2012) – PT 3.0b



Ivan (2004) – PT ??



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



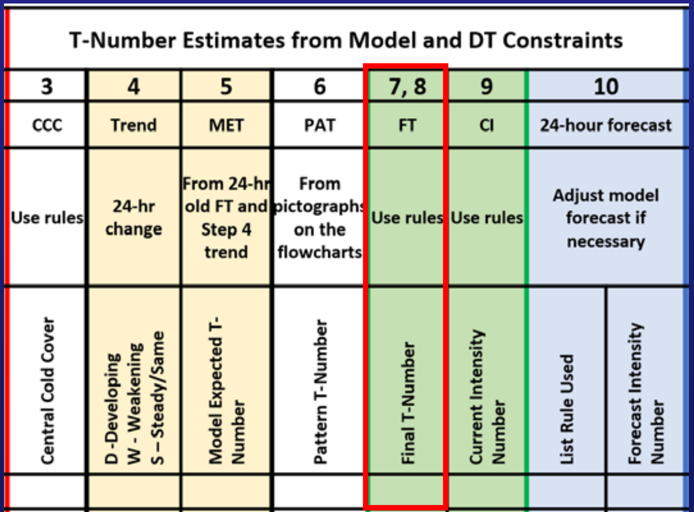
*When hatched part of these patterns is white or colder, add .5 to pattern number.

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 Estimates from Model and DT Constraints

3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/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

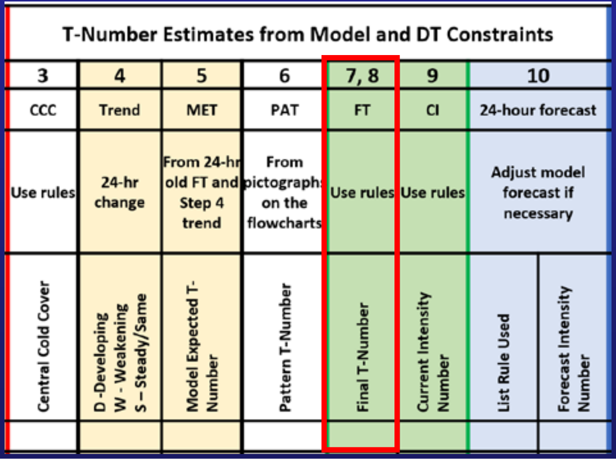
1. Initial classification must be T1 or T1.5.

2. During first 24 h of development, FT cannot be lowered at night.

3. 24 h after initial T1, FT must be ≤ 2.5.

4. Modified FT limits (next slide)

5. FT must = MET ± 1



T-Number Estimates from Model and DT Constraints

3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictograph on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number

Note: The CI never constrains the FT!

Step 8 - FT Number Change Limits

For early development: 0.5 T-numbers over 6 h

<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 h or more after the initial T1) (Pike NHC study):</th></tr>
<tr><td colspan="2">1.0 T-numbers over 6 h
1.5 T-numbers over 12 h
2.0 T-numbers over 18 h (Now 2.5)
2.5 T-numbers over 24 h (Now 3.0)</td></tr>
</table>

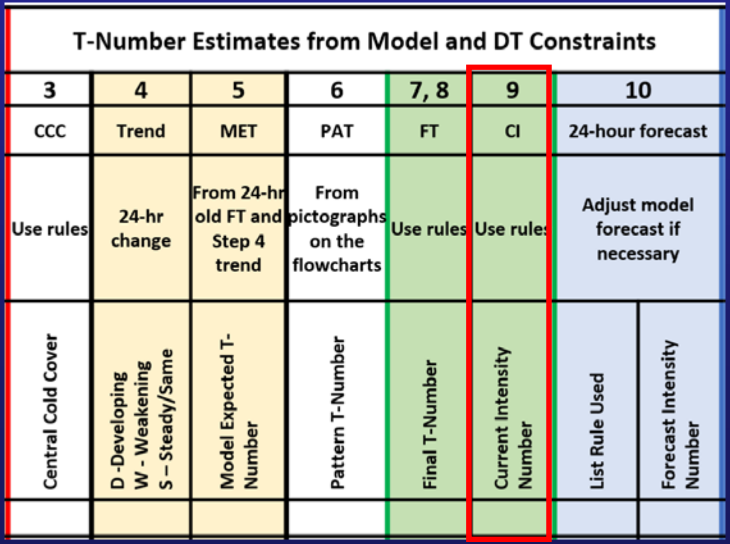
These are the maximum changes in FT number allowed over the given time periods.

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 h, but <u>never</u> more than 1.0 above the current FT

CI is never < FT!



T-Number Estimates from Model and DT Constraints

3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern T-Number	Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number

Step 9 - CI Examples

(6 h 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 h 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 h 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 h

Why are there constraints on the FT and CI?

Weak systems sometimes lose all convection during the diurnal minimum.

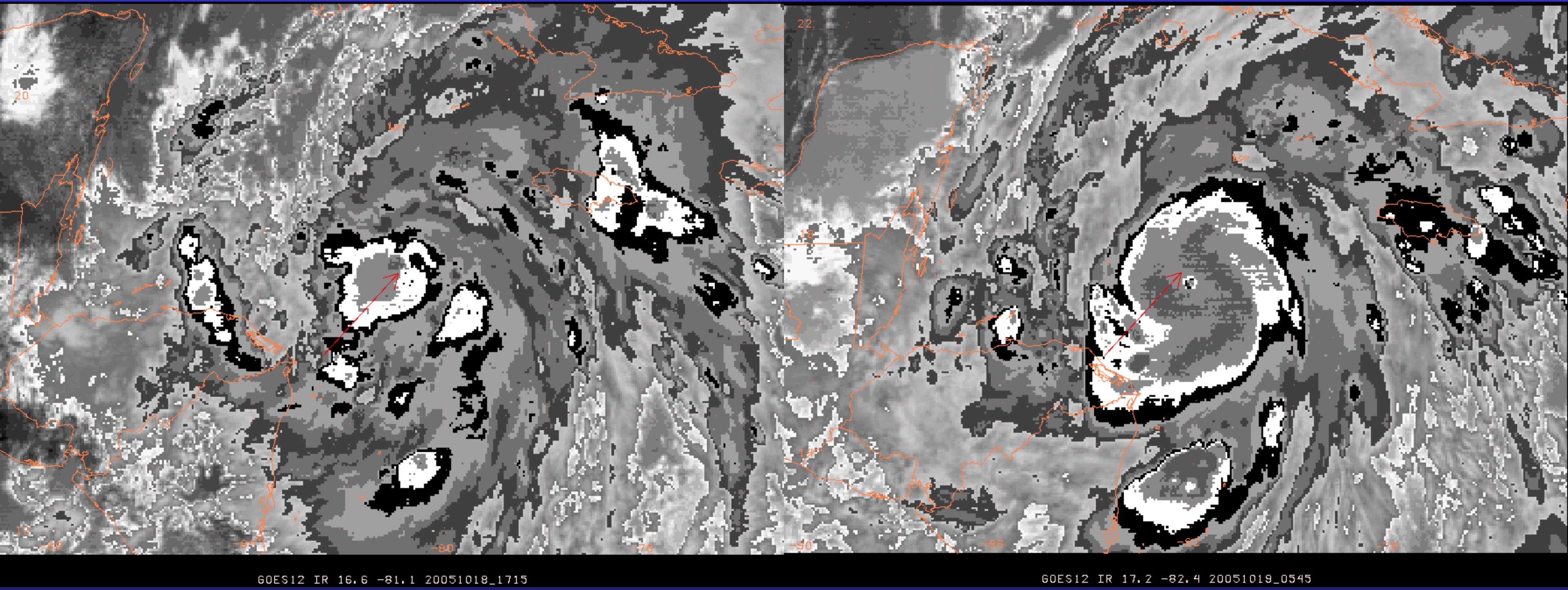
Cloud patterns for weak systems sometimes look unrealistically strong.

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!

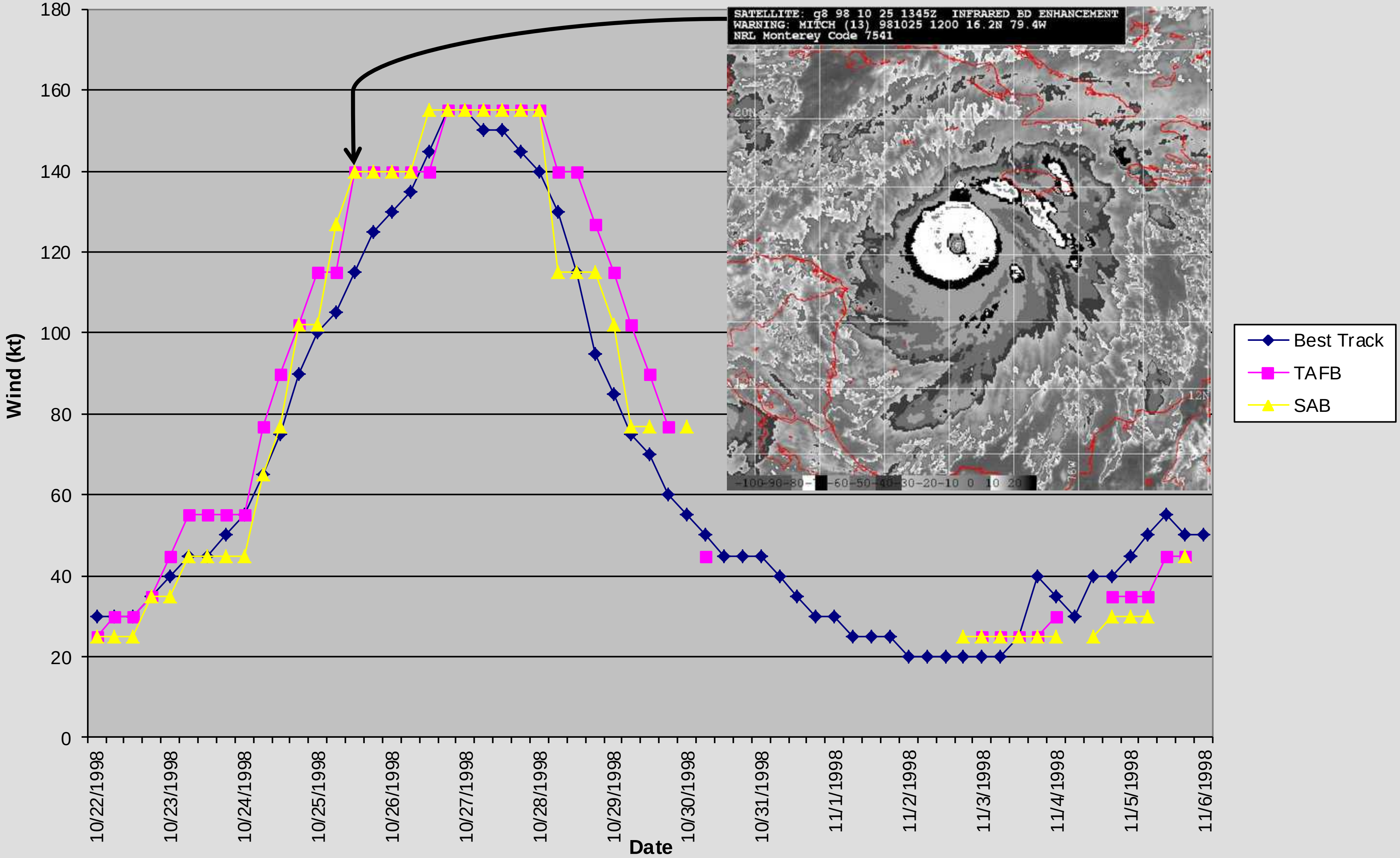
Hurricane Wilma (2005)



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

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

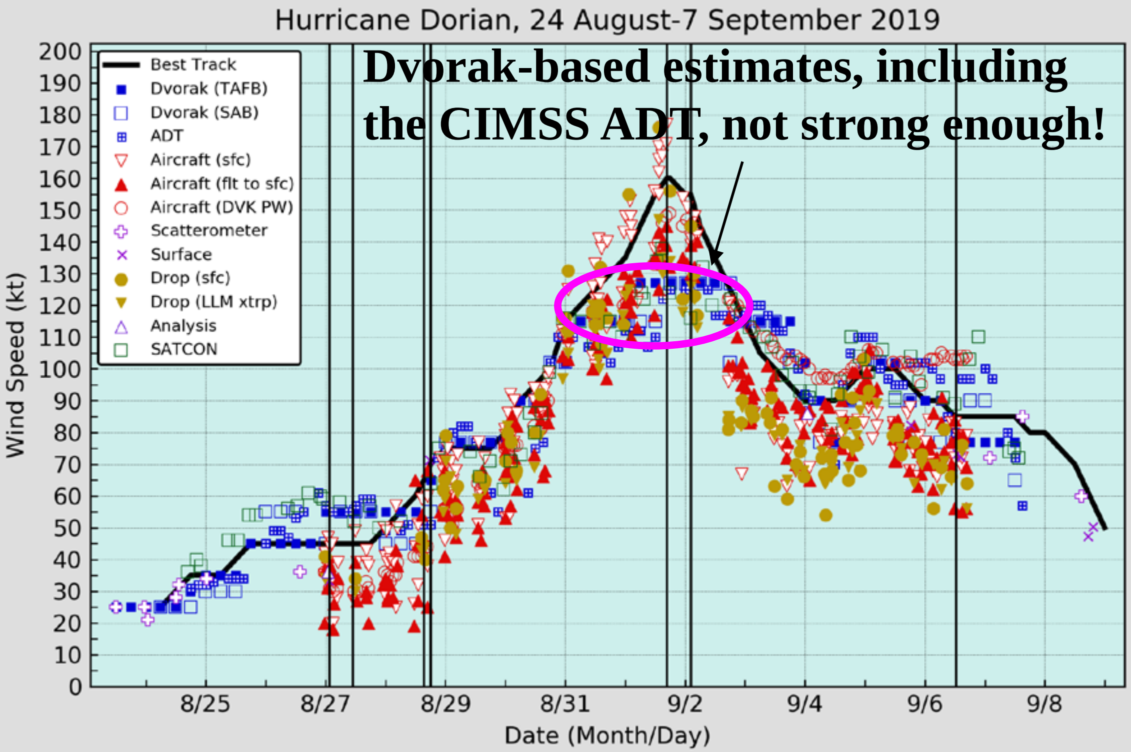
Hurricane Mitch (1998)



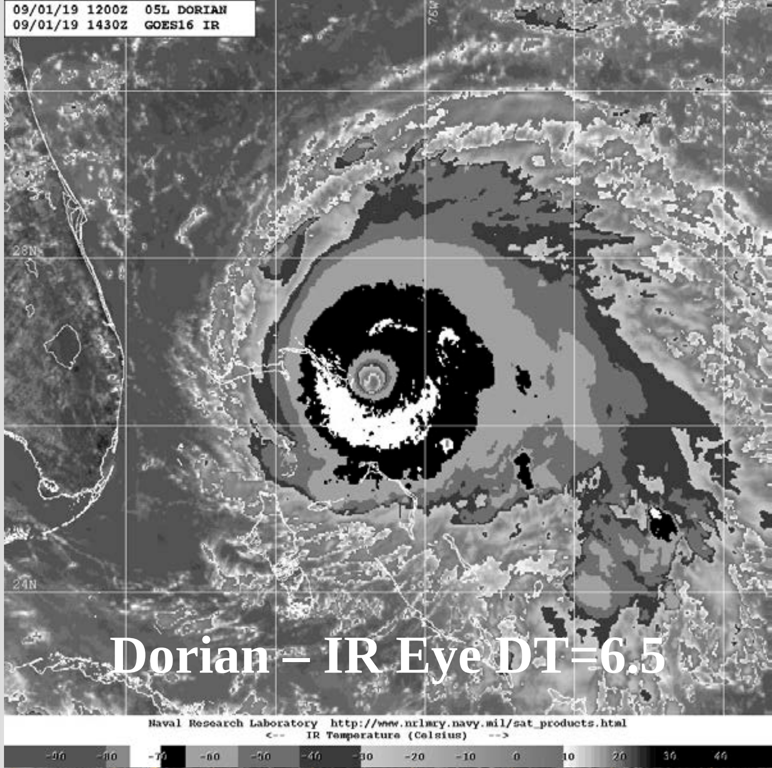
1998 Mitch BT vs. Fix Intensity

Air recon best track intensity lagged behind Dvorak estimates during intensification.

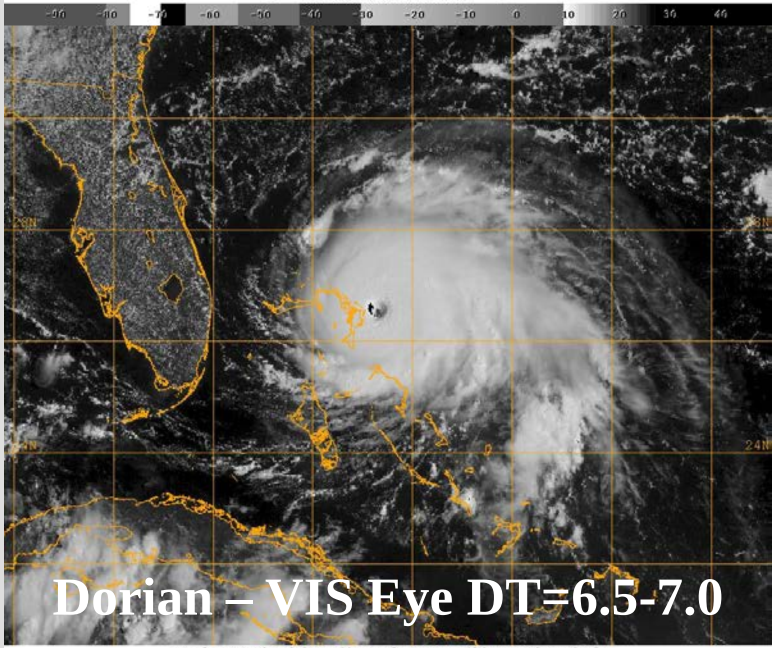
Cyclones Stronger Than They Appeared



Dvorak-based estimates, including the CIMSS ADT, not strong enough!



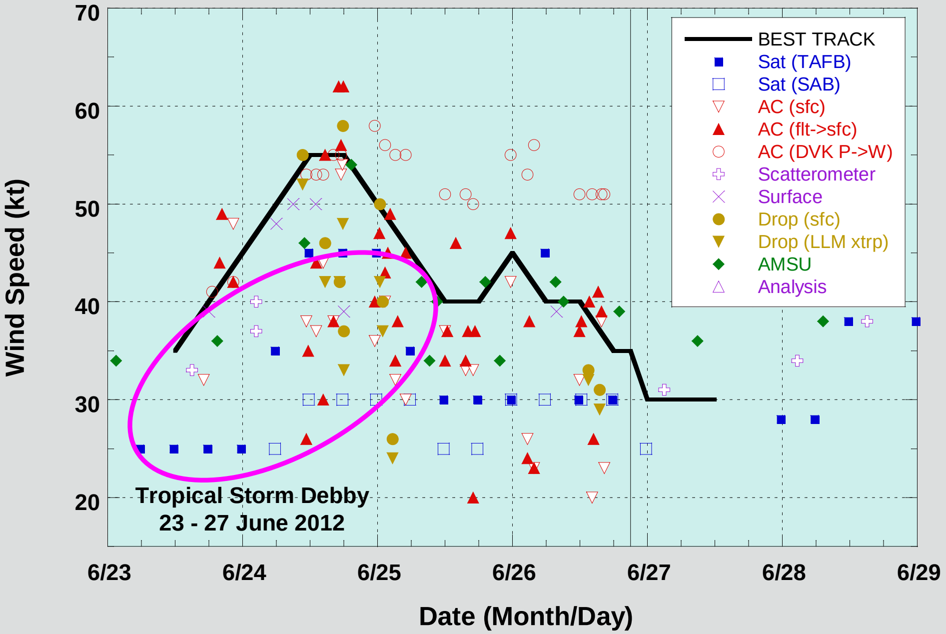
Dorian – IR Eye DT=6.5

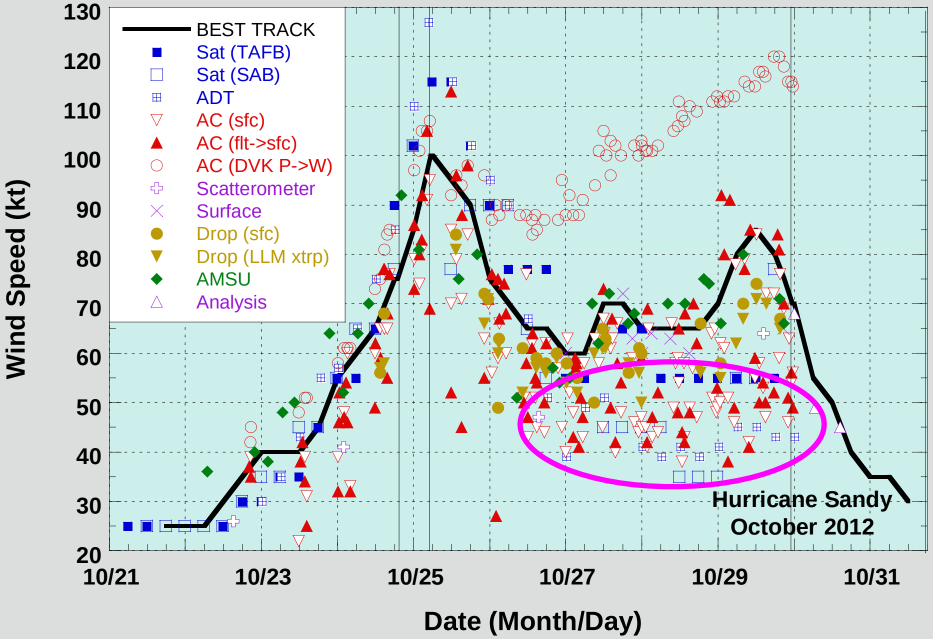


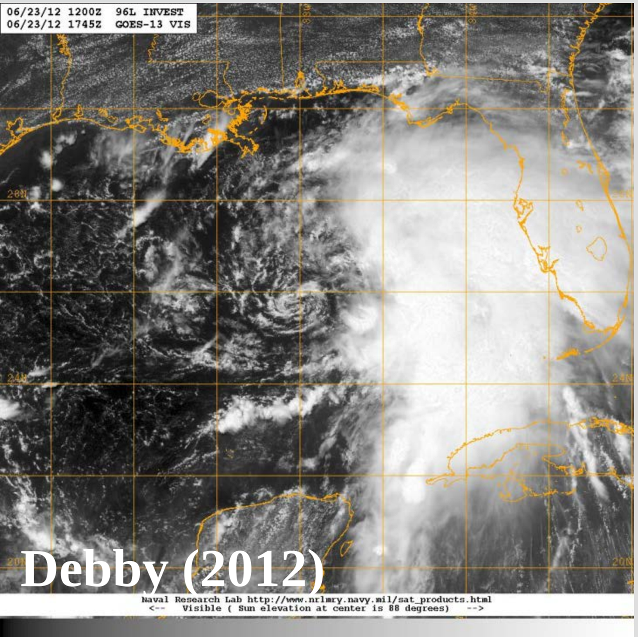
Dorian – VIS Eye DT=6.5-7.0

At peak intensity, Dorian was stronger than its Dvorak satellite signature, as was Andrew in 1992.

Cyclones Stronger Than They Appeared





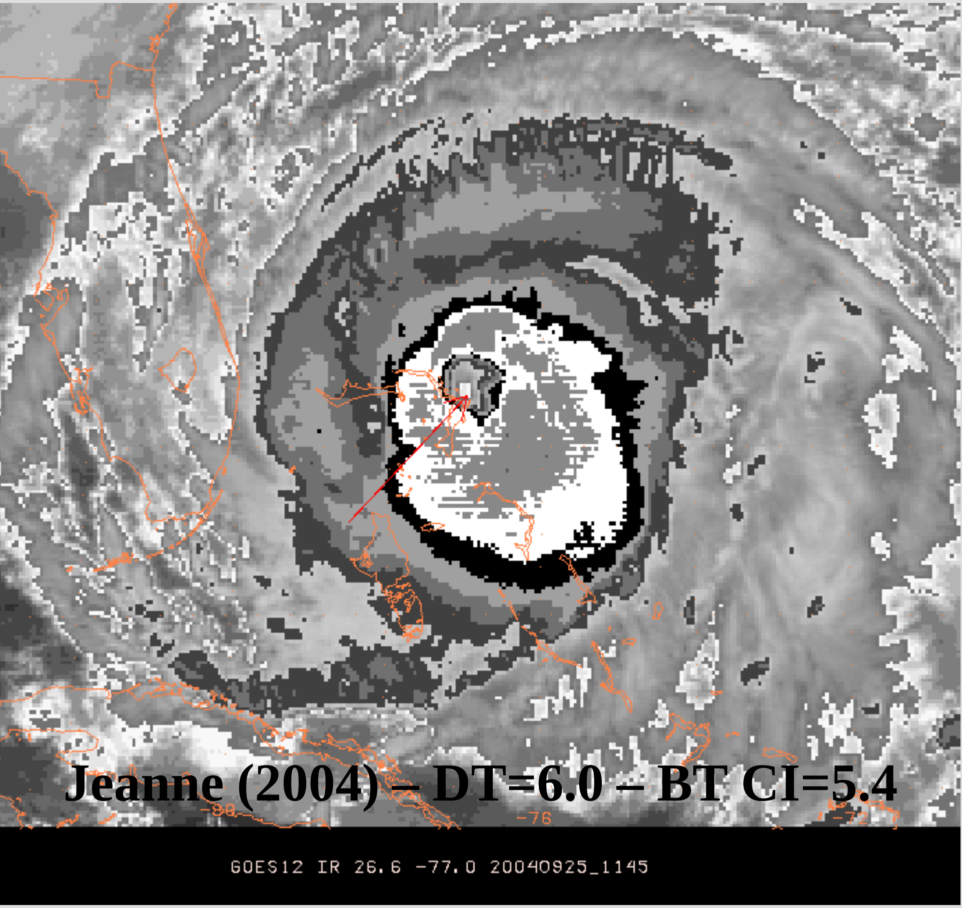


Debby (2012)

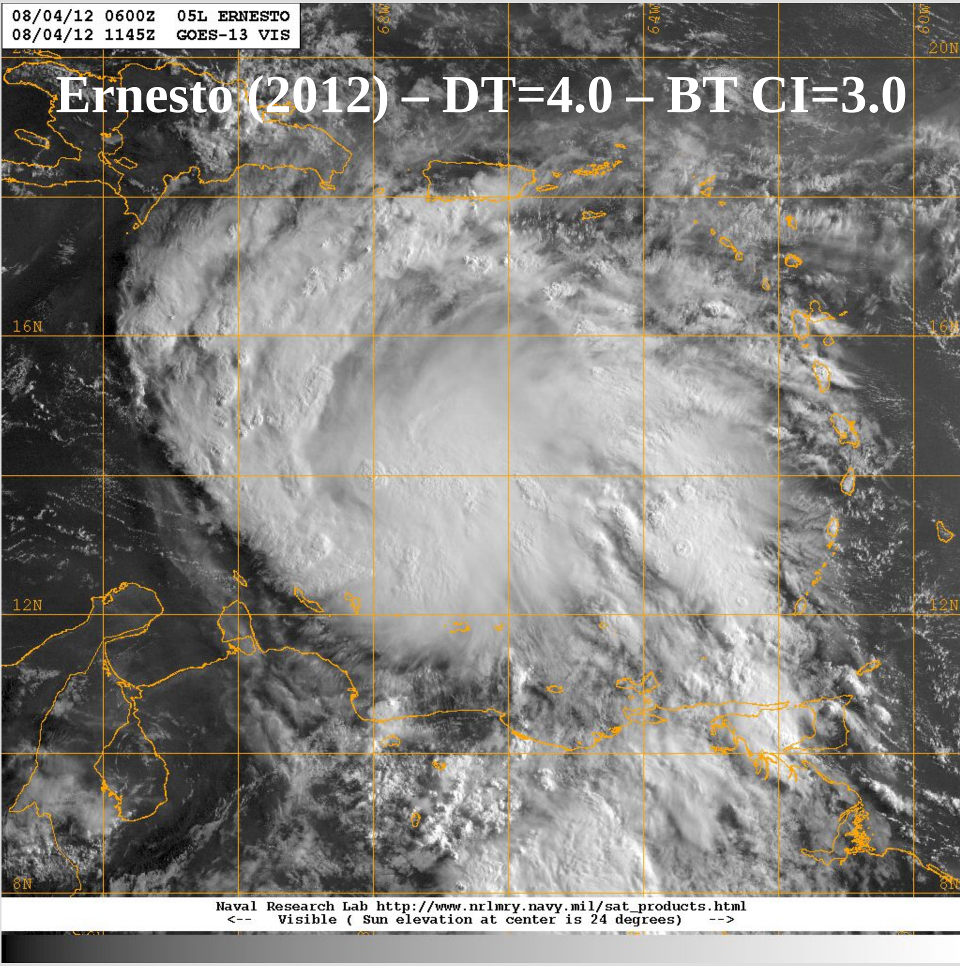
Reconnaissance data showed Debby and Sandy were stronger than their Dvorak intensity estimates. Dvorak estimates are less reliable for monsoonish cyclones (Debby) and partly baroclinic cyclones (Sandy).

Sandy (2012)

False Alarm Strong Appearances



Jeanne (2004) – DT=6.0 – BT CI=5.4

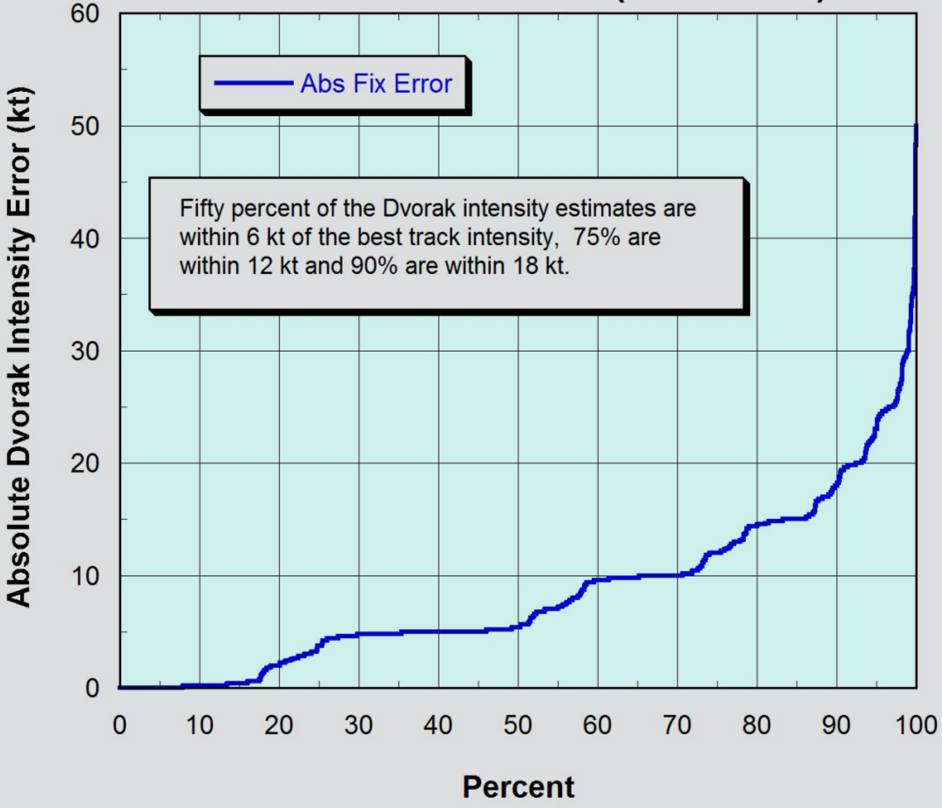


Ernesto (2012) – DT=4.0 – BT CI=3.0

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

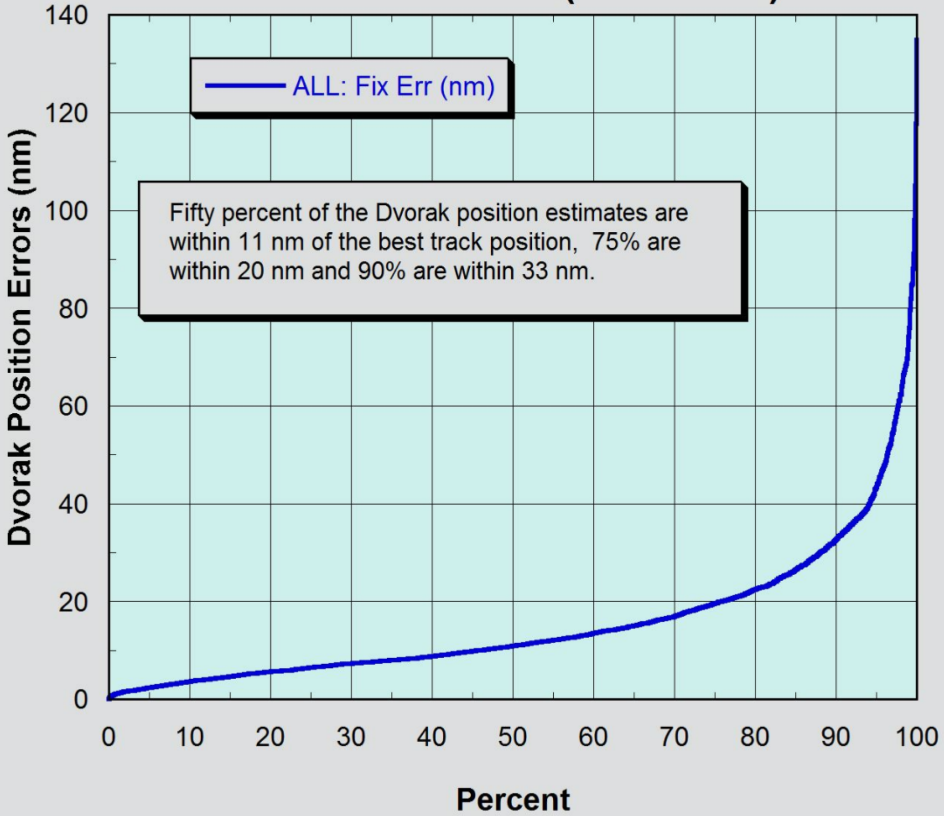
Dvorak Error Distribution

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)



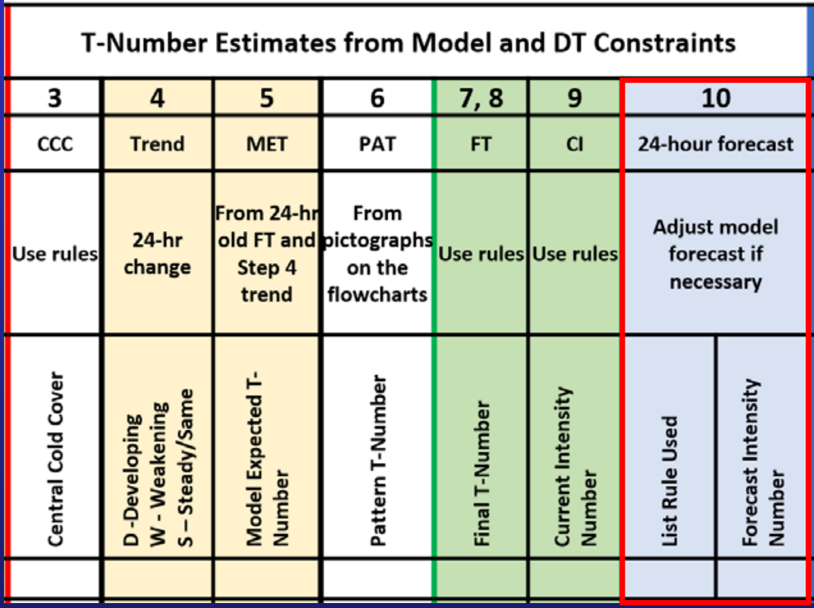
Fifty percent of the Dvorak position estimates are within 11 nm of the best track position, 75% are within 20 nm and 90% are within 33 nm.

Images courtesy of Brown and Franklin

Step 10 - Forecast Intensity (FI)

This is a 24-h 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 Estimates from Model and DT Constraints

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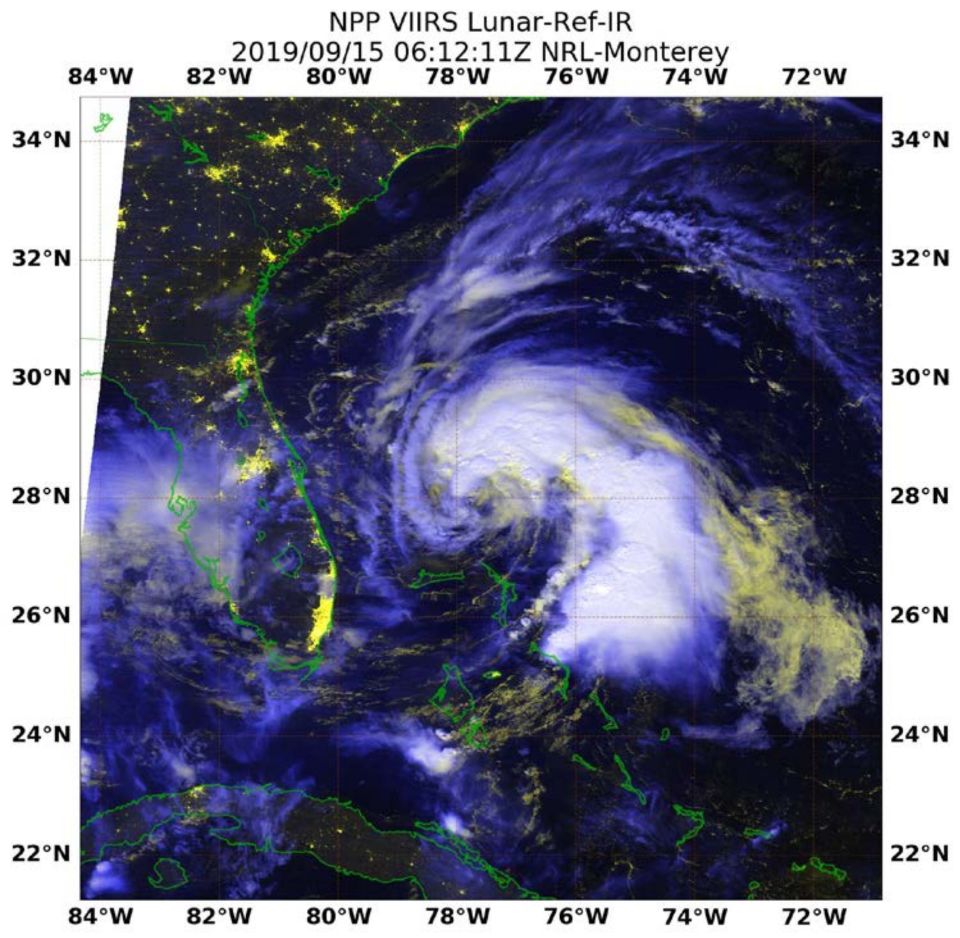
A Few More Tips

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) are sensitive enough to provide moonlight visible imagery, thus allowing use of VIS cloud patterns and center location at night



Humberto (2019) NPP VIIRS Lunar Reflectance Moonlight Visible Imagery

Related Techniques

Hebert-Poteat Subtropical Cyclones Technique

Automated/Objective Dvorak Technique

ARCHER Objective TC center location

Microwave sounding-based TC intensity estimates

Satellite Consensus (SATCON) Technique

Experimental Techniques - Microwave Data and Other Approaches

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 (formerly of 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 Cooperative Institute for Research in the Atmosphere at Colorado State University – satellite imagery and animations
- The Naval Research Laboratory, Monterey, CA – satellite images
- NASA – satellite images
- Liz Ritchie (UNSW), Margie Kieper (FIU) for related technique material