IR/Dvorak

Andrew Hagen and Jack Beven

What is the single most important tool for the National Hurricane Center in monitoring its area of responsibility?

0

A. Low Earth Orbiting Weather Satellite — 0%

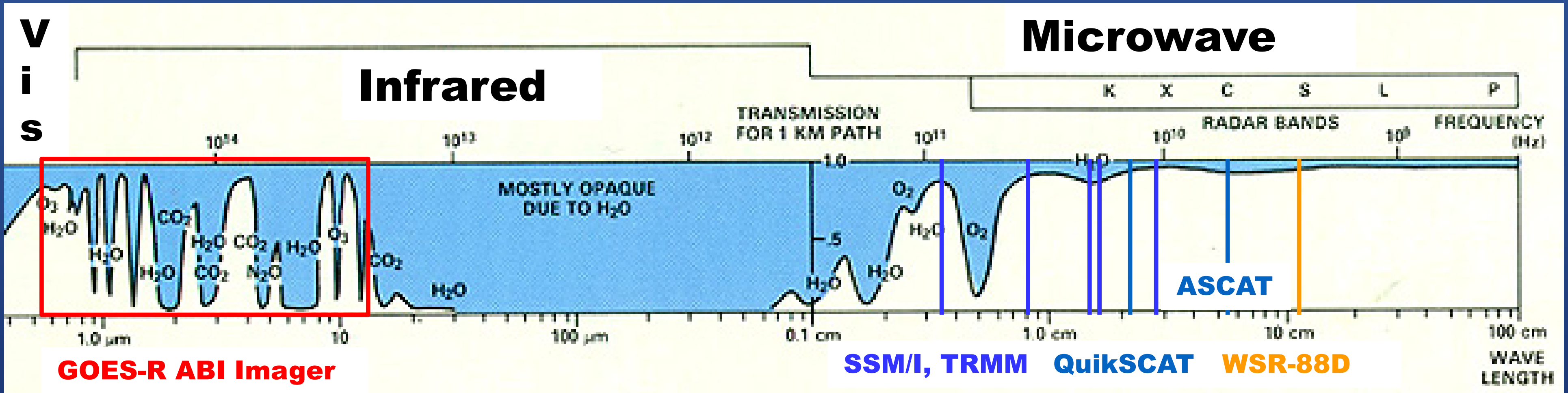
B. Reconnaissance Aircraft — 0%

C. Land-based or Aircraft Radar — 0%

D. Geostationary Weather Satellite — 0%

E. Surface Observations — 0%

Atmospheric Absorption/Emission Spectrum

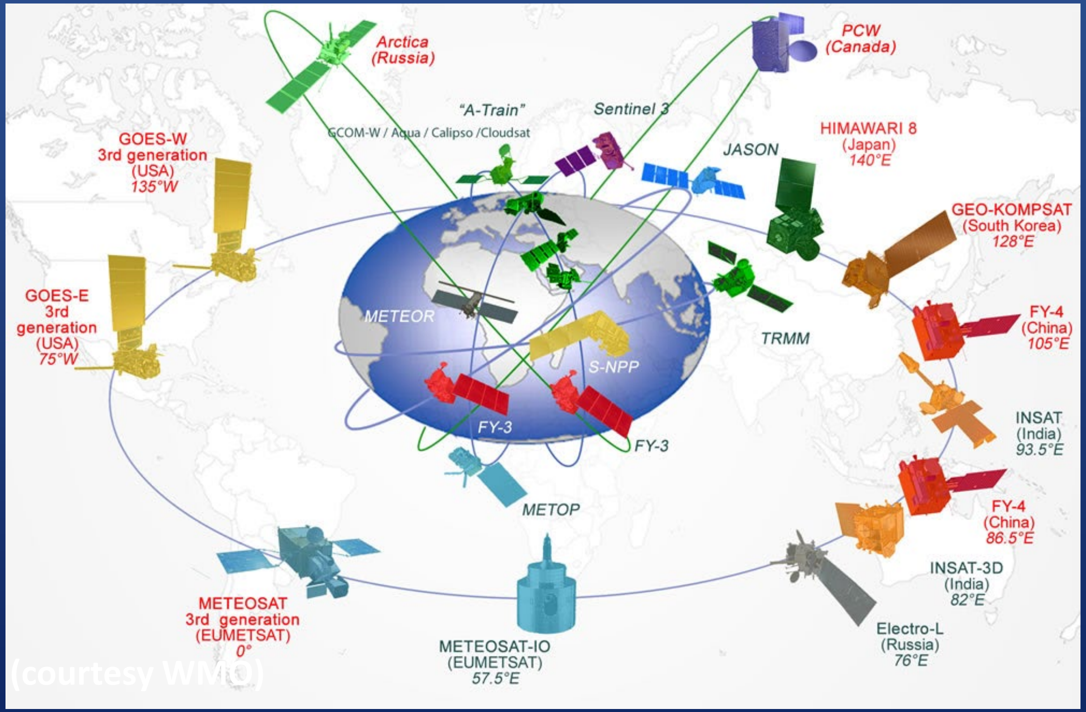


Longer wavelength

Higher frequency

Remote Sensing Satellites

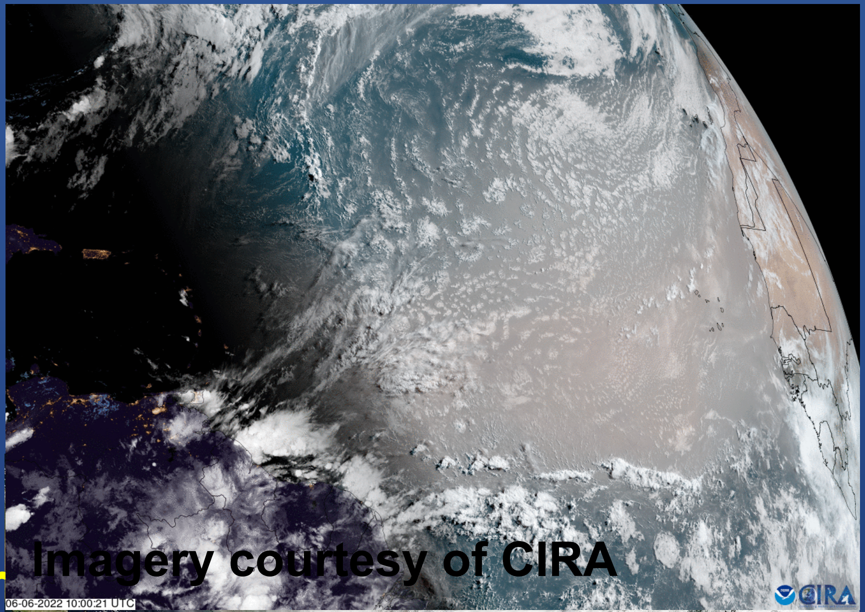
- These "look" down from a great height and can thus see more detail depending on the height above the Earth's surface.
- Remote sensing can be thought of as how to obtain information about an object of interest without being in physical contact with it.
- Satellite instruments can be designed to observe many types of atmospheric, oceanic, and land-surface phenomena based on the instrument frequencies chosen.

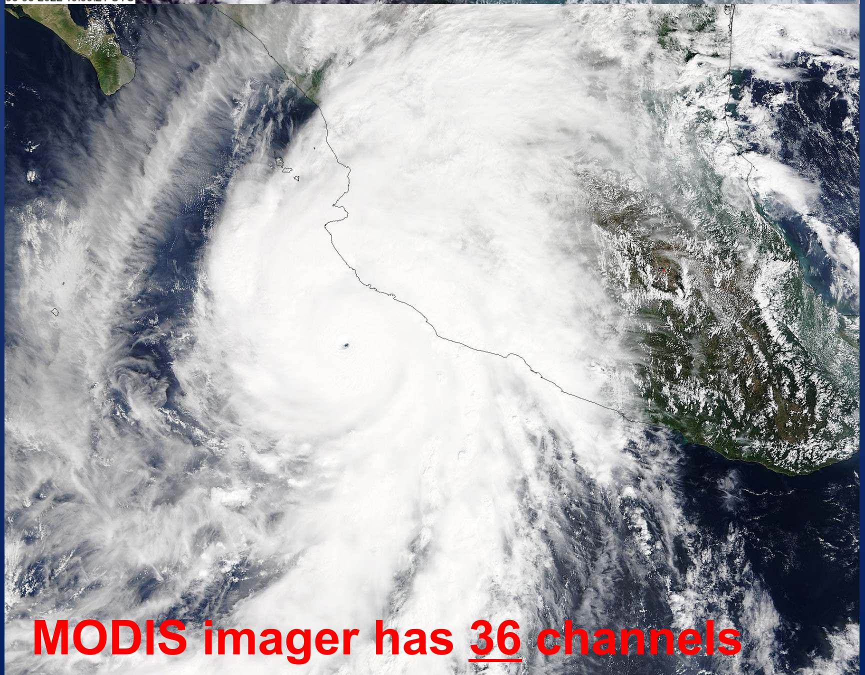


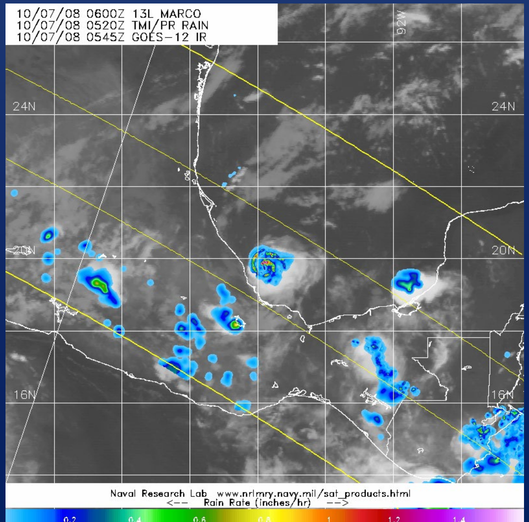
(courtesy WMO)

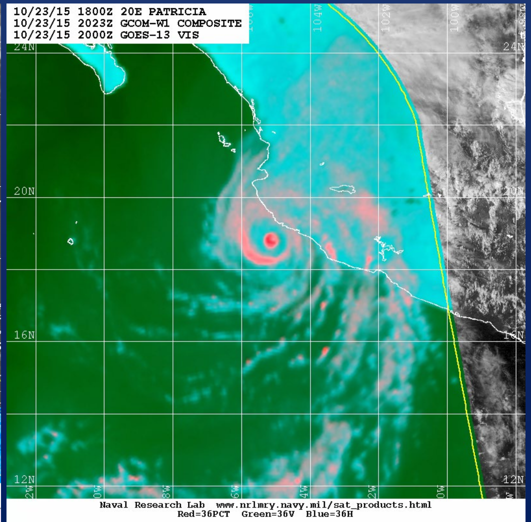
Instruments - Imagers

- An imager makes an image of some meteorological quantity.
- *Usually* use one wavelength/ frequency but can use combinations of wavelengths/ frequencies (multispectral)
- Satellite imagery is normally used for analysis and short-term forecasting.





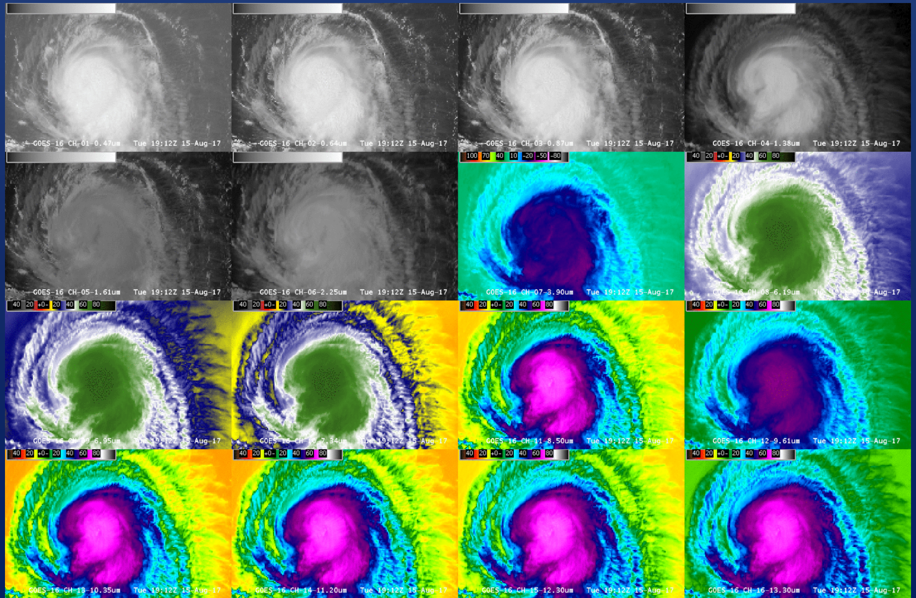




The ABI Imager

- 16 channel imager, including 11 channels not flown on GOES 13-15
- Increased spatial and spectral resolution over the current GOES imagers

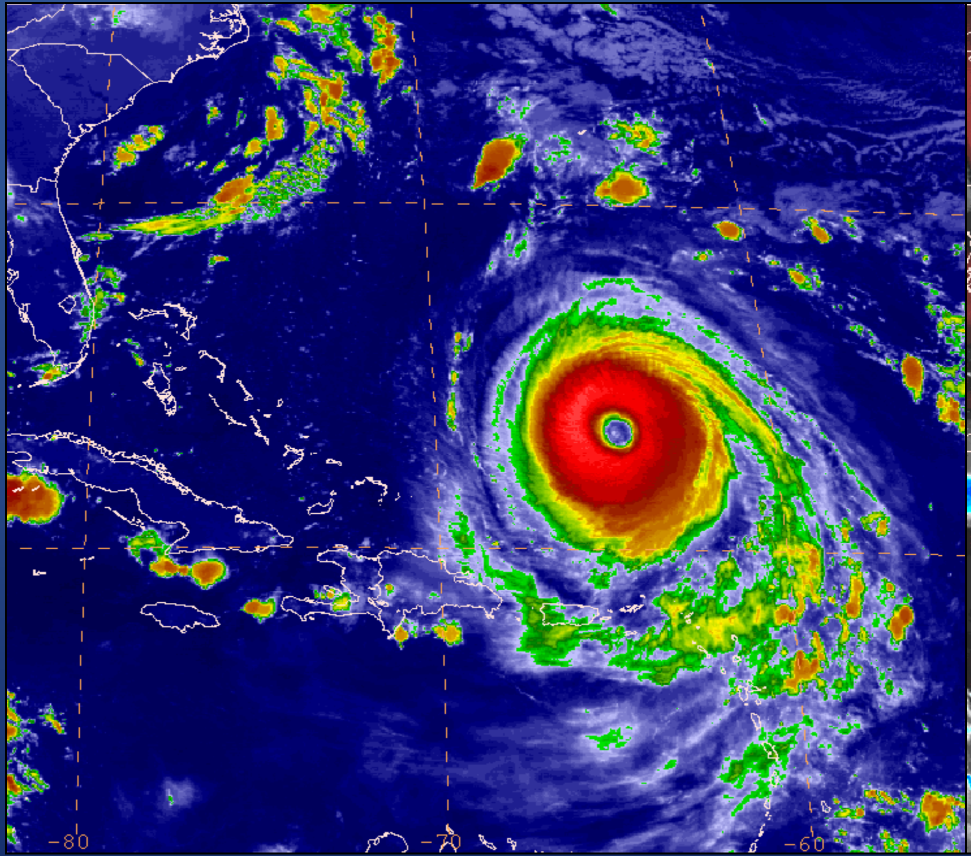
Table courtesy of Tim Schmit, CIMSS
GOES-16 Imagery below courtesy of CIMSS



GOES-R ABI Imager Channels

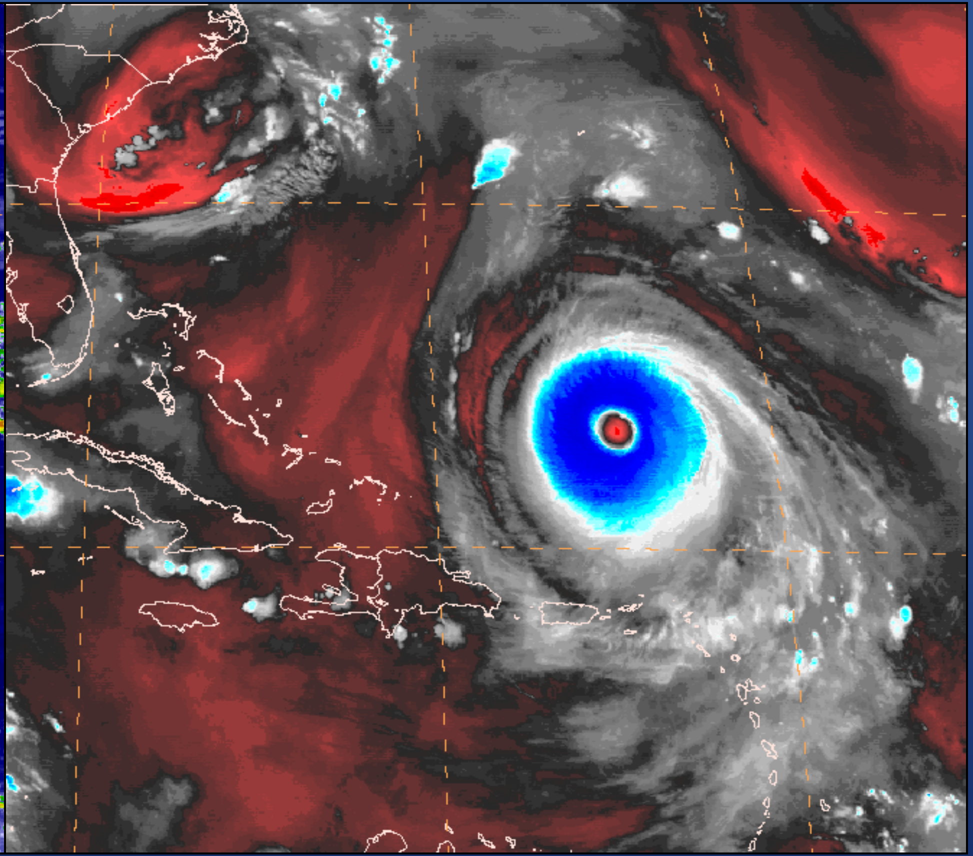
Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping
* 2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds
4	1.371–1.386	1.378	2	Daytime cirrus cloud
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow
* 7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall
* 9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds
13	10.1–10.6	10.35	2	Surface and cloud
* 14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall
* 15	11.8–12.8	12.3	2	Total water, ash, and SST
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts

Are we looking at levels or layers?



Conventional IR 10.7 µm

More of a level quantity.



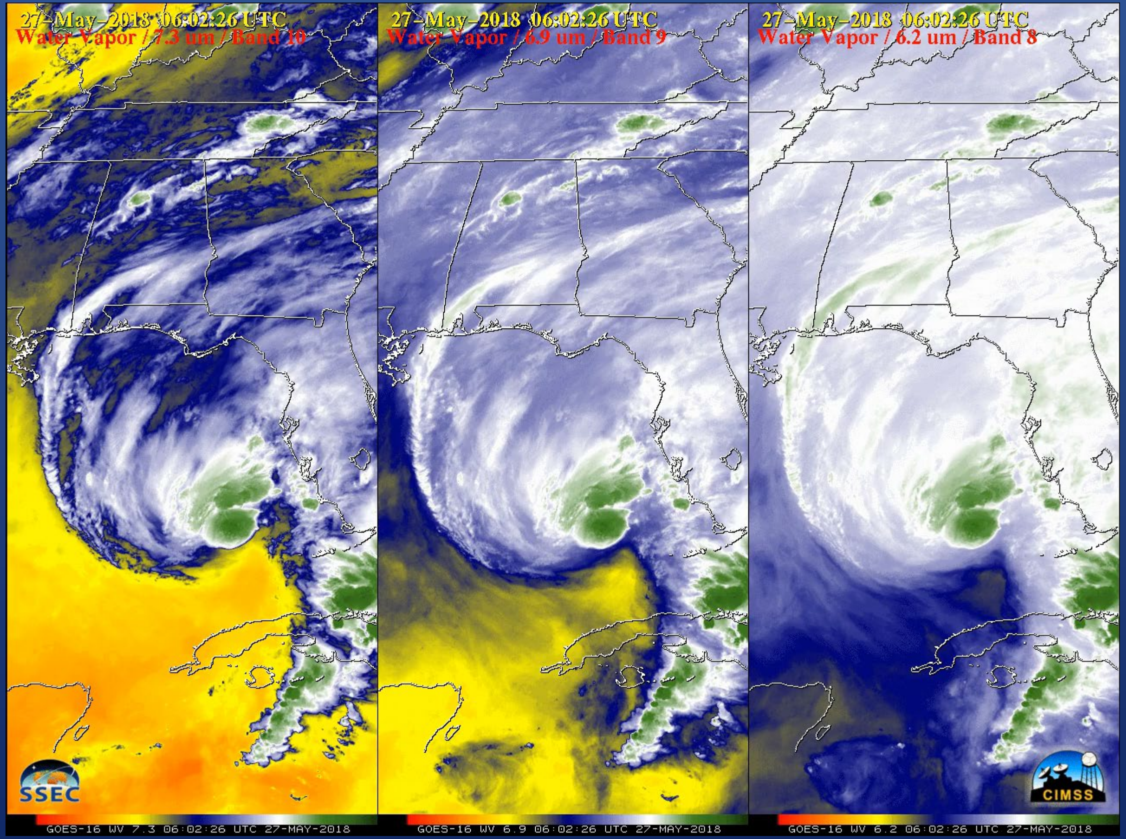
Water Vapor IR 6.5 µm

More of a layer quantity.

GOES-12 0600 UTC 14 Sep 2003

Water Vapor Imagery

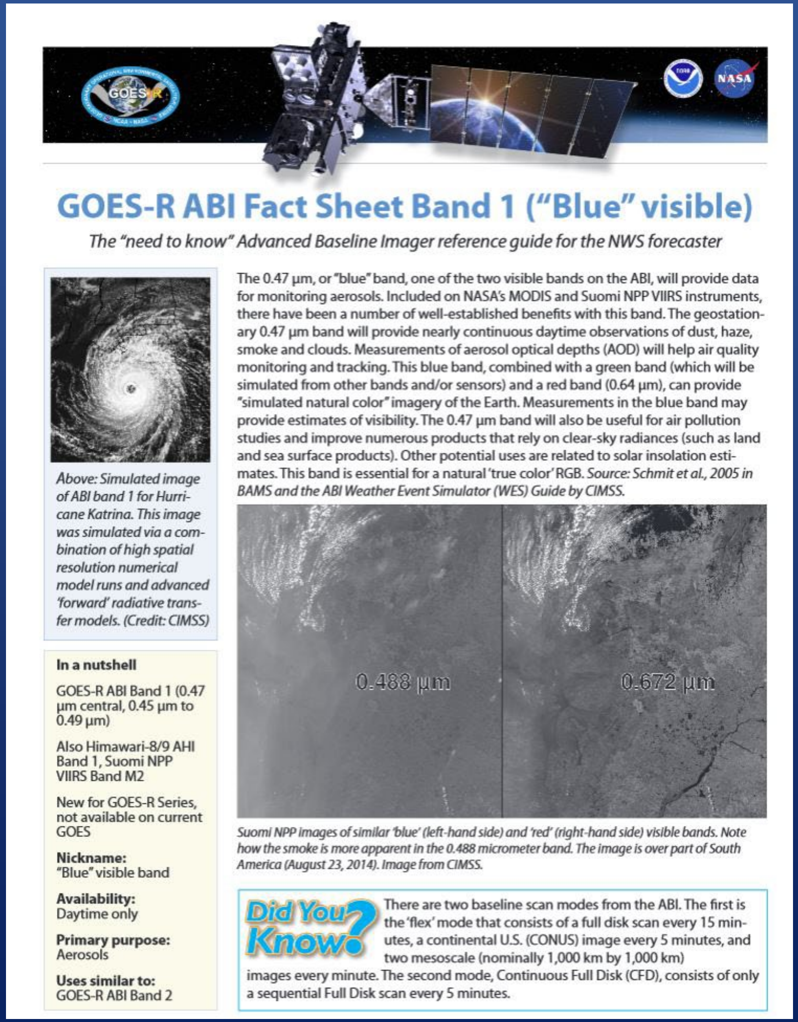
- λ =6.5 μm is sensitive to water vapor in the mid to upper troposphere (generally 200-500 mb).
- Other wavelengths have peak sensitivity at other levels – the ABI has three channels for low/mid/ high-level water vapor.
- Water vapor imagery can reveal features that don't generate visible clouds.
- Animation can reveal steering flows, shearing winds, dry intrusions, or outflow for TCs.



Alberto (2018) GOES WV channels (courtesy CIMSS)

Additional Training for GOES-R

- **GOES-R Training Portal -** http://www.goes-r.gov/users/training.html
- **COMET MetEd Course -** https://www.meted.ucar.edu/training_course.php?id=42
- **CIRA Training Course for GOES-R -** http://rammb.cira.colostate.edu/training/visit/training_sessions/satfc-g.asp
- **ABI Facts Sheets -** http://www.goes-r.gov/education/ABI-bands-quick-info.html
- **CIRA Satellite Library -** https://satlib.cira.colostate.edu
- **CIMSS Satellite Blog -** http://cimss.ssec.wisc.edu/goes/blog/



GOES-R ABI Fact Sheet Band 1 ("Blue" visible)

The "need to know" Advanced Baseline Imager reference guide for the NWS forecaster

The 0.47 µm, or "blue" band, one of the two visible bands on the ABI, will provide data for monitoring aerosols. Included on NASA's MODIS and Suomi NPP VIIRS instruments, there have been a number of well-established benefits with this band. The geostationary 0.47 µm band will provide nearly continuous daytime observations of dust, haze, smoke and clouds. Measurements of aerosol optical depths (AOD) will help air quality monitoring and tracking. This blue band, combined with a green band (which will be simulated from other bands and/or sensors) and a red band (0.64 µm), can provide "simulated natural color" imagery of the Earth. Measurements in the blue band may provide estimates of visibility. The 0.47 µm band will also be useful for air pollution studies and improve numerous products that rely on clear-sky radiances (such as land and sea surface products). Other potential uses are related to solar insolation estimates. This band is essential for a natural 'true color' RGB. *Source: Schmit et al., 2005 in BAMS and the ABI Weather Event Simulator (WES) Guide by CIMSS.*

Above: Simulated image of ABI band 1 for Hurricane Katrina. This image was simulated via a combination of high spatial resolution numerical model runs and advanced 'forward' radiative transfer models. (Credit: CIMSS)

0.488 µm 0.672 µm

Suomi NPP images of similar 'blue' (left-hand side) and 'red' (right-hand side) visible bands. Note how the smoke is more apparent in the 0.488 micrometer band. The image is over part of South America (August 23, 2014). Image from CIMSS.

In a nutshell

GOES-R ABI Band 1 (0.47 µm central, 0.45 µm to 0.49 µm)

Also Himawari-8/9 AHI Band 1, Suomi NPP VIIRS Band M2

New for GOES-R Series, not available on current GOES

Nickname: "Blue" visible band

Availability: Daytime only

Primary purpose: Aerosols

Uses similar to: GOES-R ABI Band 2

Did You Know? There are two baseline scan modes from the ABI. The first is the 'flex' mode that consists of a full disk scan every 15 minutes, a continental U.S. (CONUS) image every 5 minutes, and two mesoscale (nominally 1,000 km by 1,000 km) images every minute. The second mode, Continuous Full Disk (CFD), consists of only a sequential Full Disk scan every 5 minutes.

NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION

NCEP

NATIONAL WEATHER SERVICE

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.

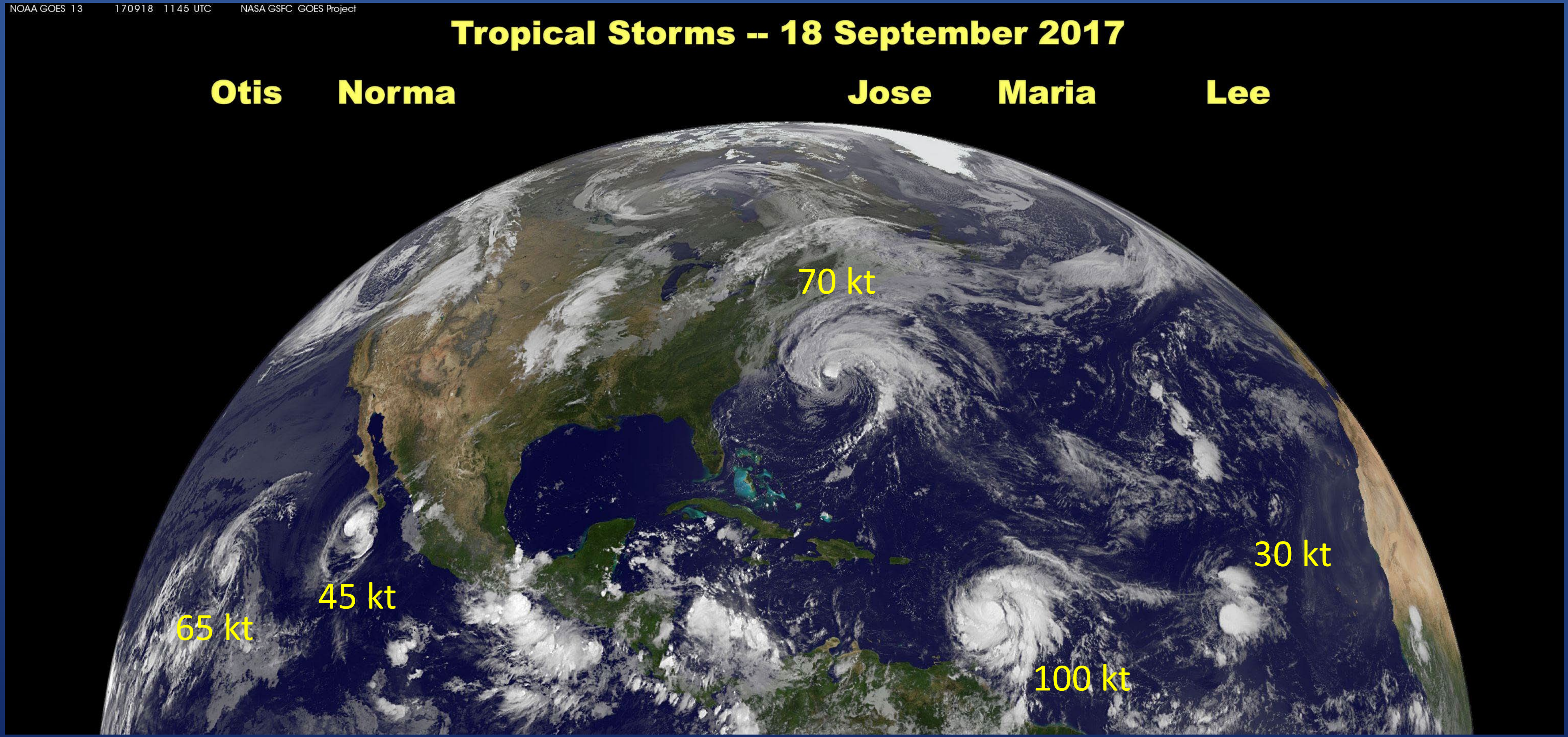
What the Dvorak Technique isn't!

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

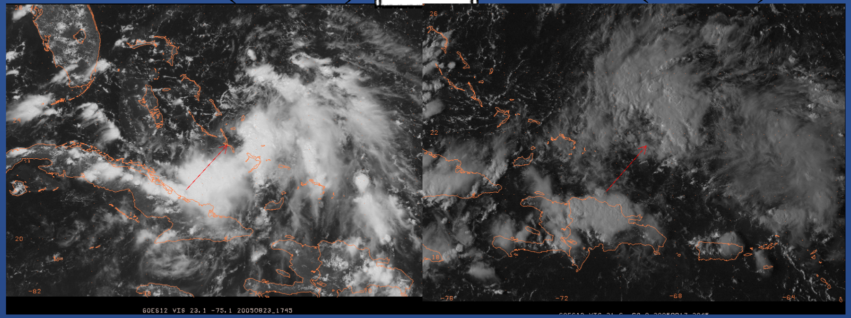
Dvorak Technique Premise

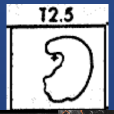


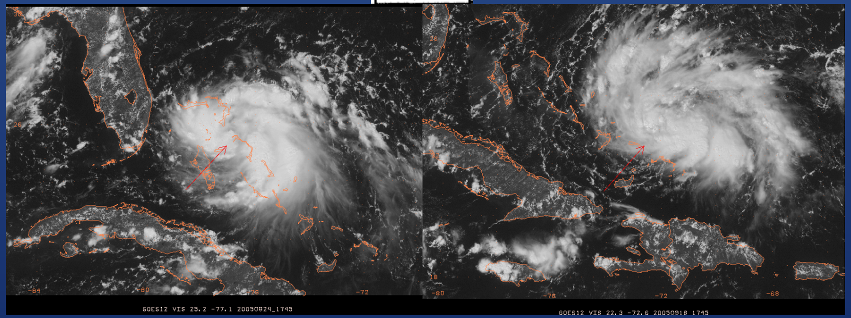
There is a (imperfect) correlation between the intensity of a TC and its satellite observed cloud pattern during both development and decay.

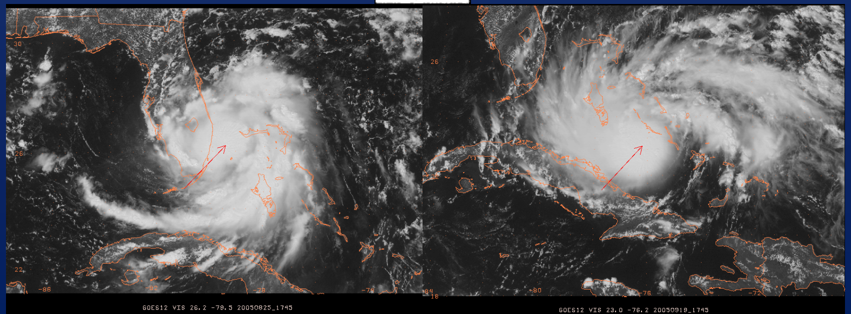
TC Cloud Patterns – Developing

Katrina (2005) Rita (2005)

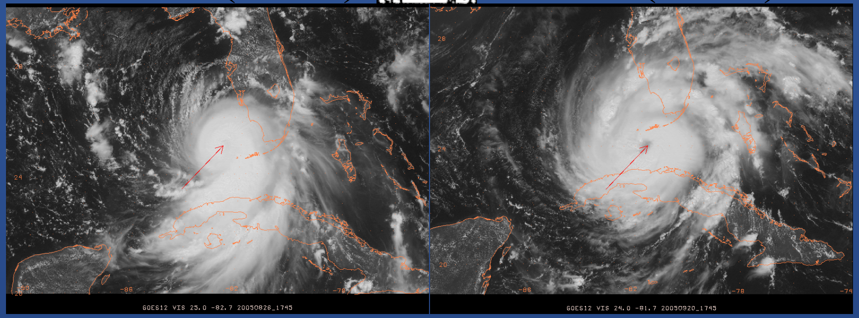


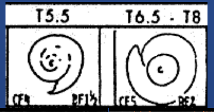


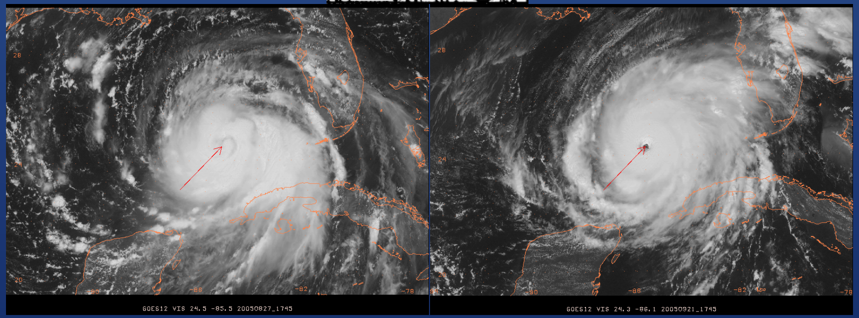


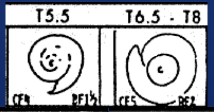


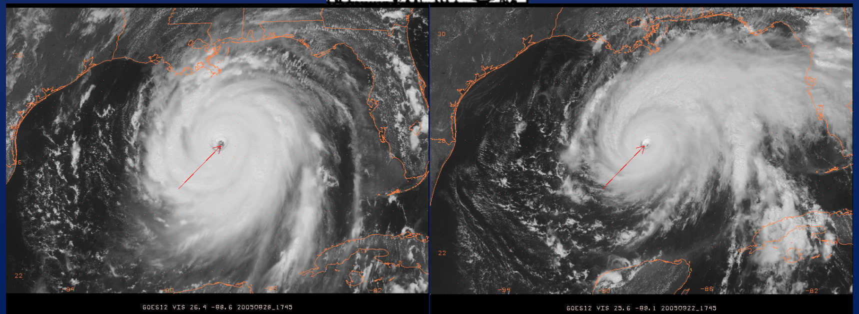
Katrina (2005) Rita (2005)





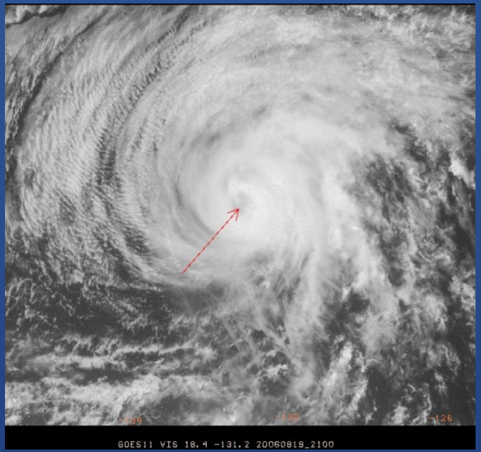




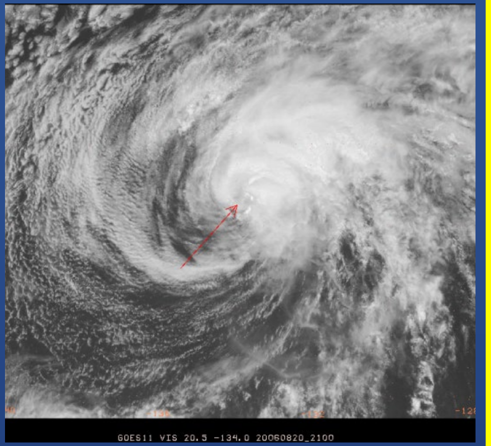


TC Cloud Patterns - Weakening

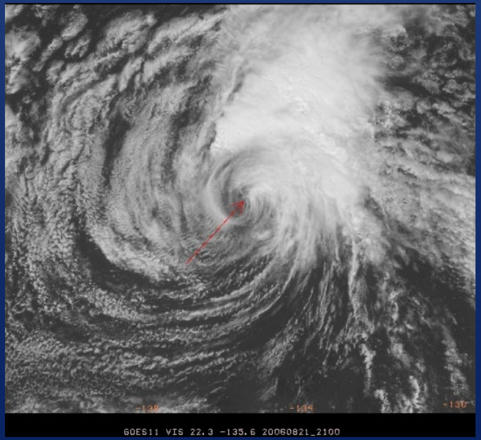
Hector 2006



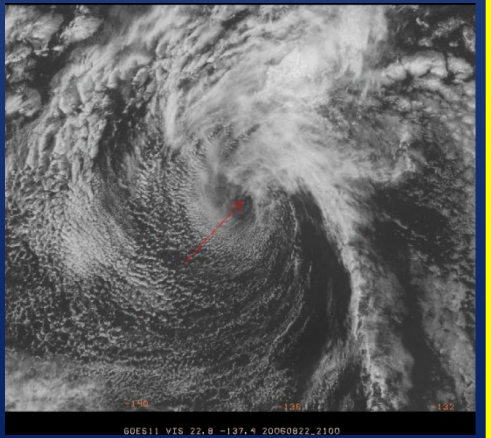
19 Aug. 2100 UTC



20 Aug. 2100 UTC

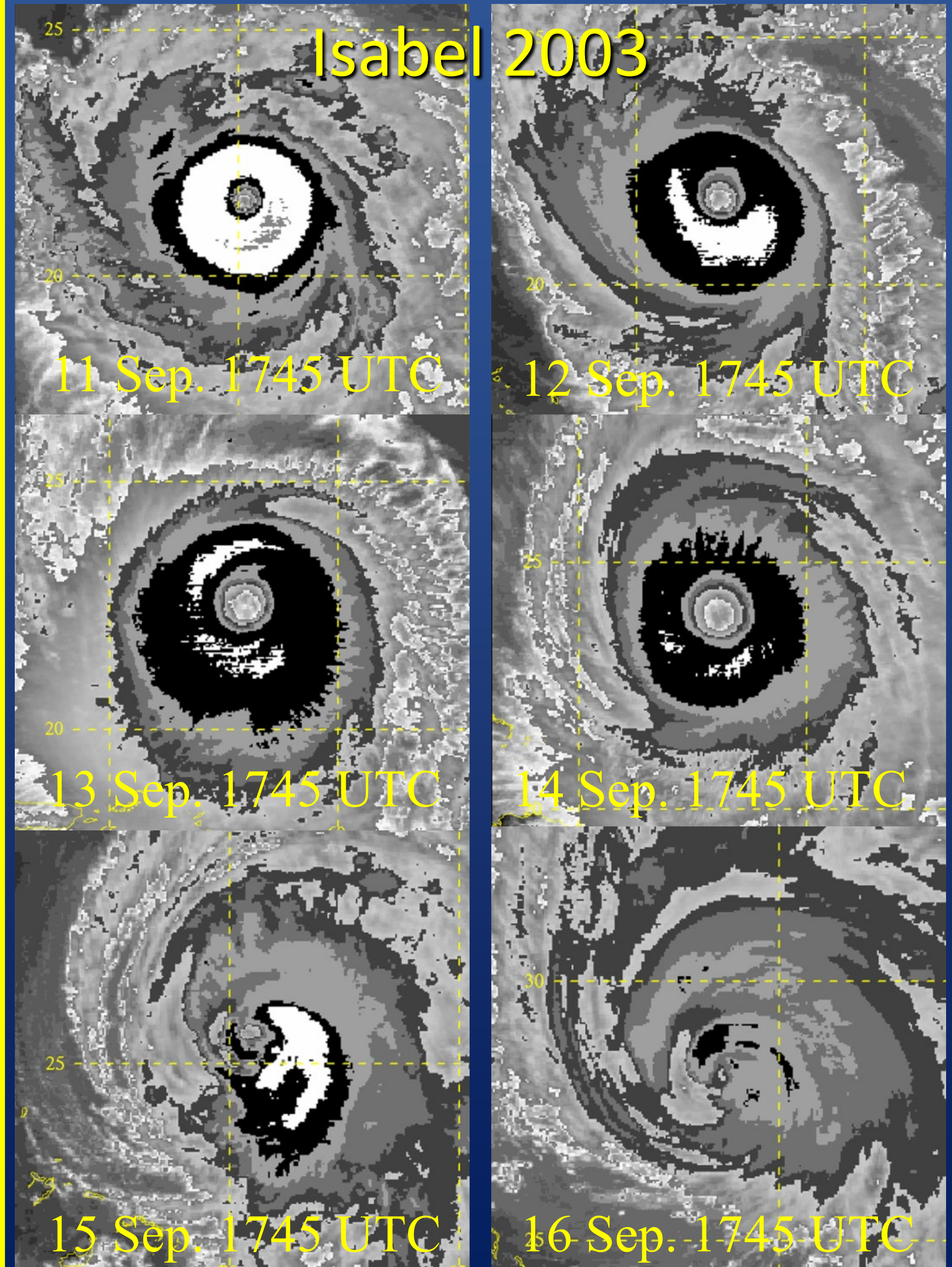


21 Aug. 2100 UTC

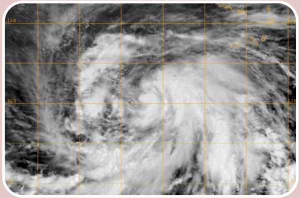


22 Aug. 2100 UTC

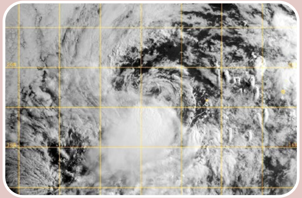
Isabel 2003



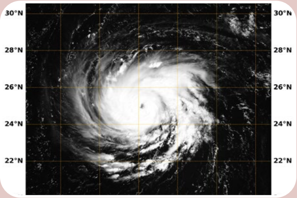
Dvorak Technique Cloud Patterns



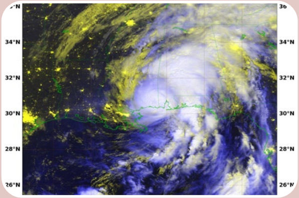
Curved Band (VIS and IR)



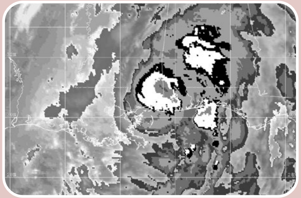
Shear (VIS and IR)



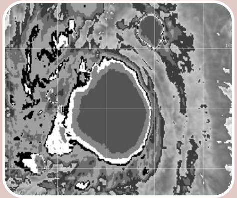
Eye (VIS and IR)



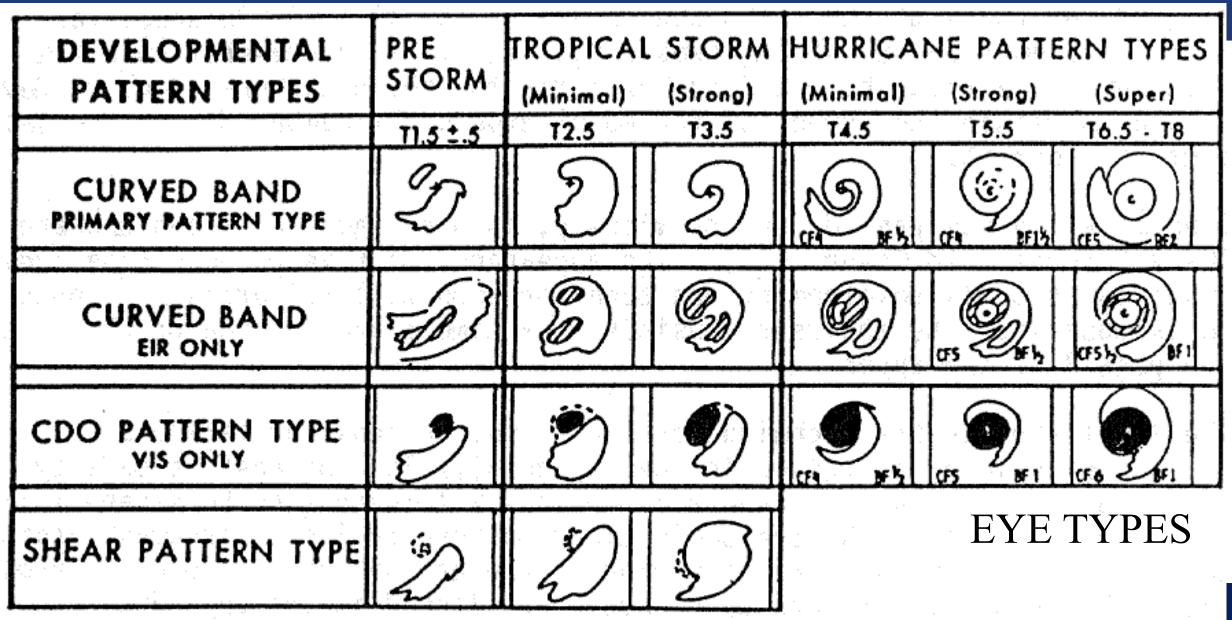
Central Dense Overcast (VIS)

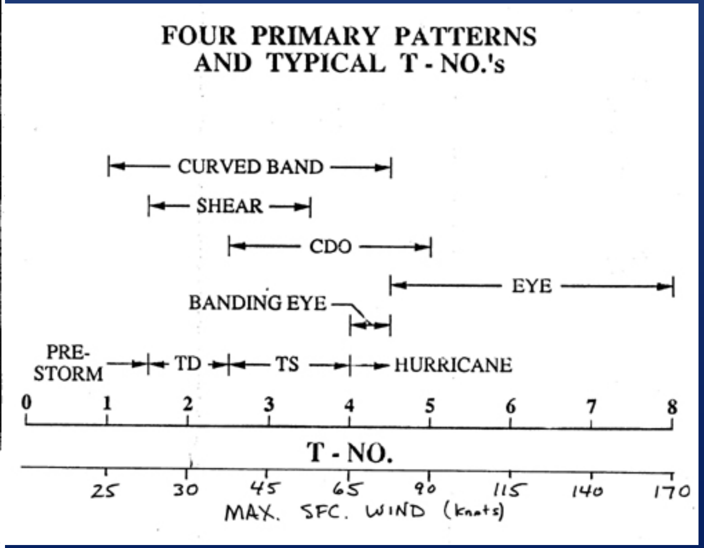


Embedded Center (IR)



Central Cold Cover (VIS and IR)





T-Numbers: How to Quantify the Cloud Patterns

The Dvorak Technique quantifies TC intensity on a 1-8 scale (at 0.5 intervals) called T-Numbers, which are used in a variety of ways.

The final output of the technique is the Current Intensity (CI) number.

↑

The CI number is driven by the Final-T (FT) Number.

↑

In turn, the FT is driven by the Data-T (DT) number, the Model Expected-T (MET) number, and the Pattern-T (PT or PAT) number.

↑

The DT is often created from other sub-numbers.

Dvorak Technique Output

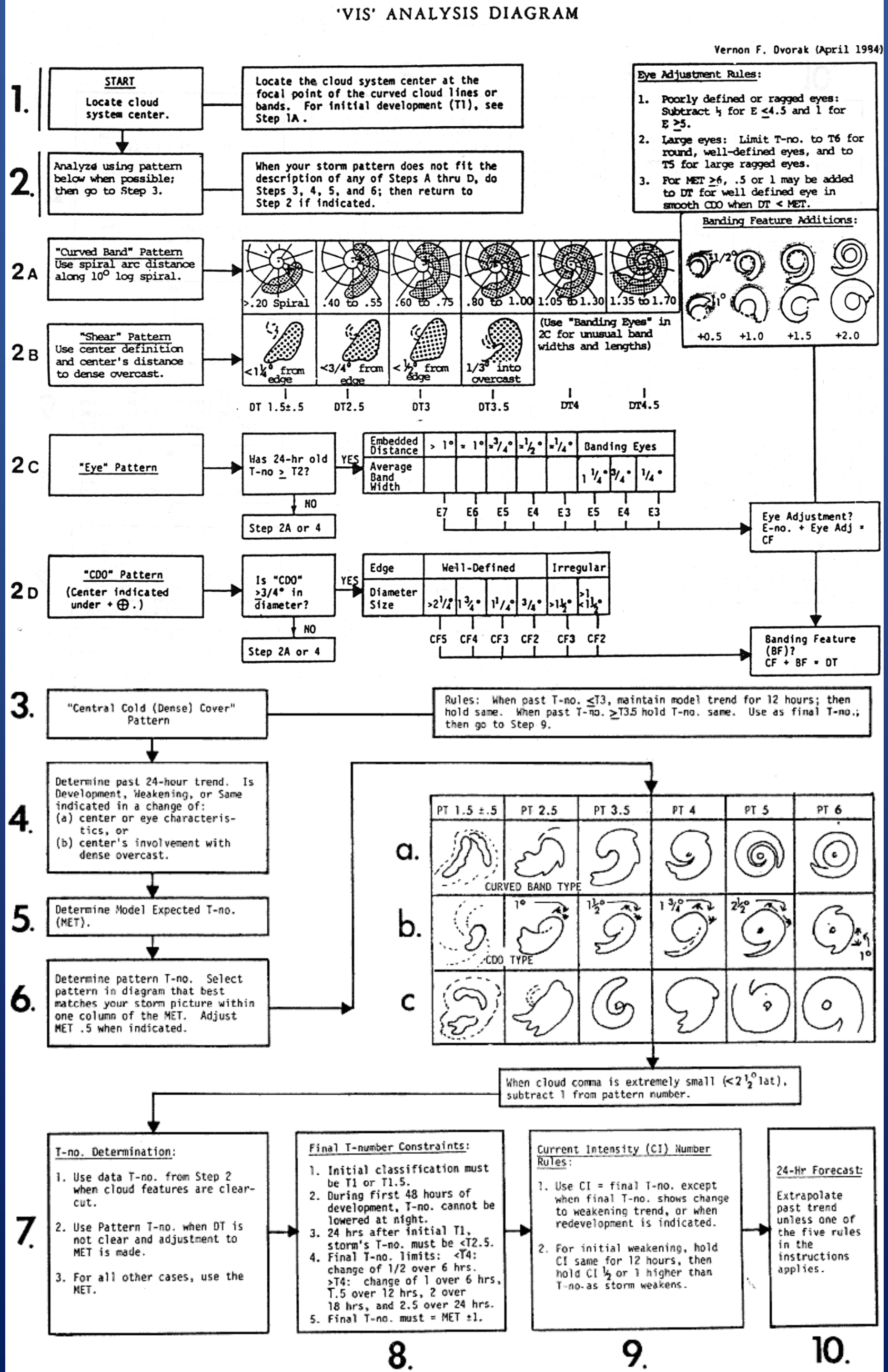
	1-minute MSW				NHC/CPHC/JTWC	
CI Number	(kt)	(mph)	(km/ h)	(m/s)	MSLP (ATL/EPAC)	MSLP (NW Pacific)
1.0	25	29	46	13		
1.5	25	29	46	13		
2.0	30	35	56	15	1009 mb	1000 mb
2.5	35	40	65	18	1005 mb	997 mb
3.0	45	52	83	23	1000 mb	991 mb
3.5	55	63	102	28	994 mb	984 mb
4.0	65	75	120	33	987 mb	976 mb
4.5	77	89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



Step 1 - Locate the Cloud System Center (CSC)

Locate the overall pattern center.

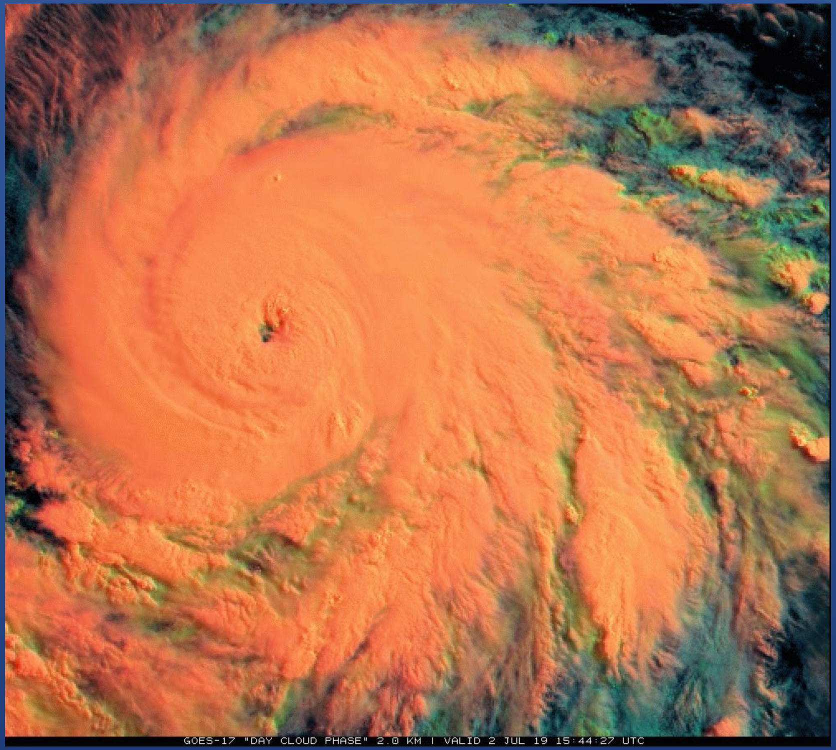
Look for small scale features.

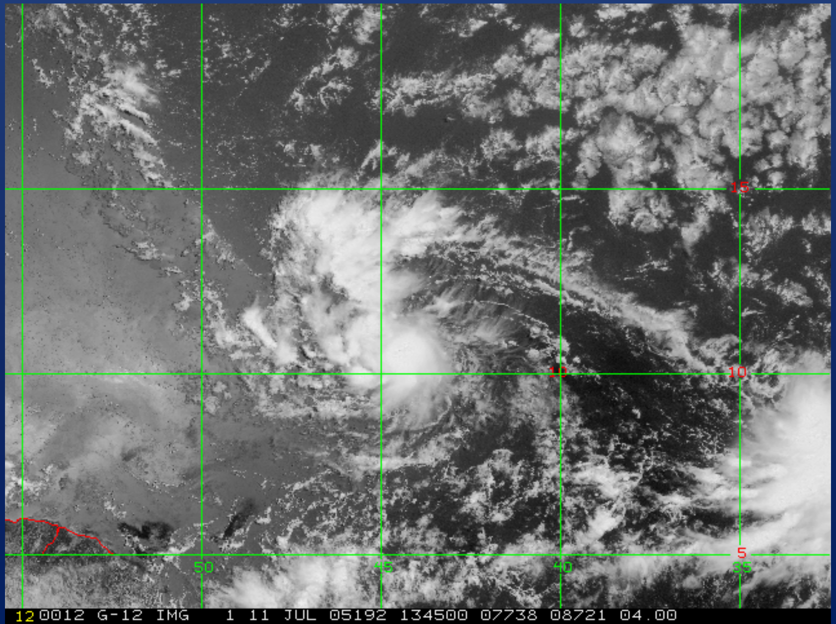
Compare center location with forecast.

Compare center with previous pattern center.

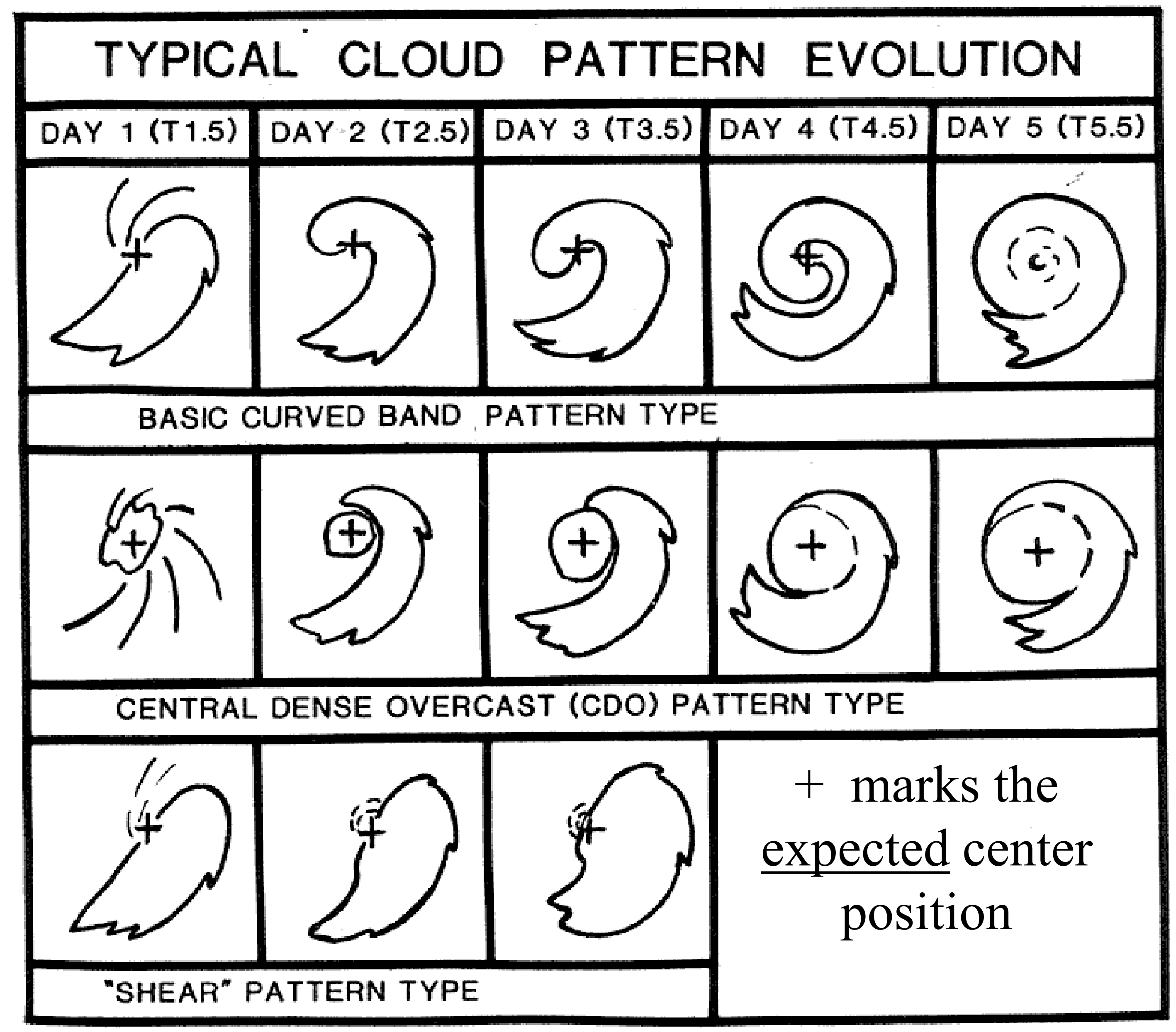
Make final location adjustments.

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





Expected CSC Positions



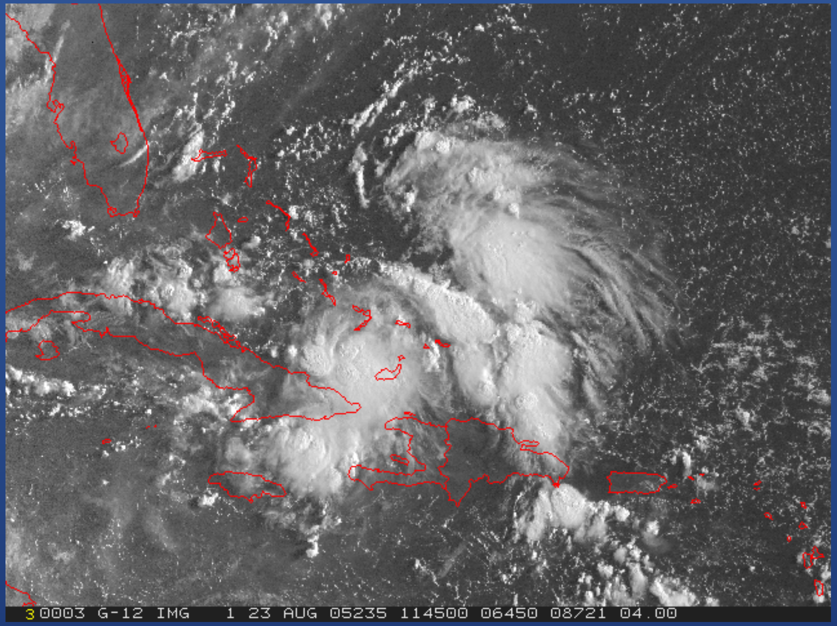
Animated Imagery

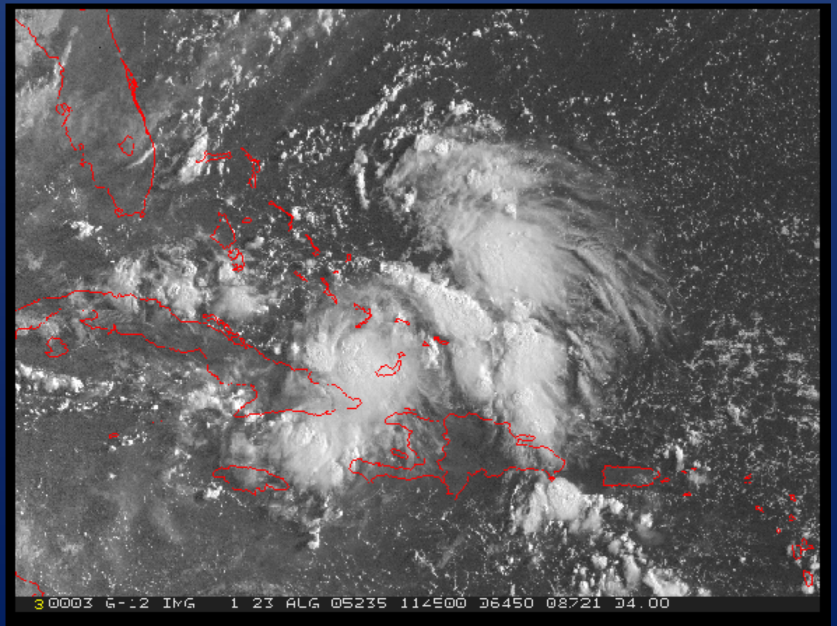
The technique center finding principles were designed for single images and not animation.

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!

Step 2 – Analyze the cyclone cloud pattern

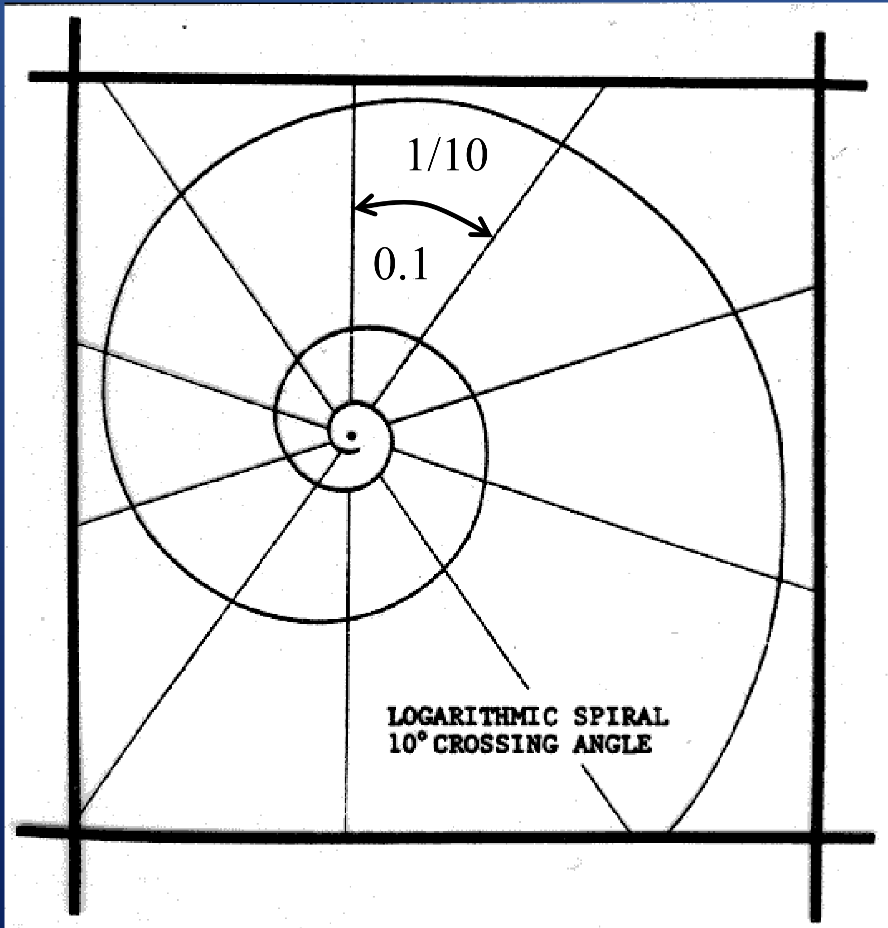
The cloud pattern analysis produces the Data-T (DT) number intensity estimate.

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.



Step 2A – Measuring Curved Bands

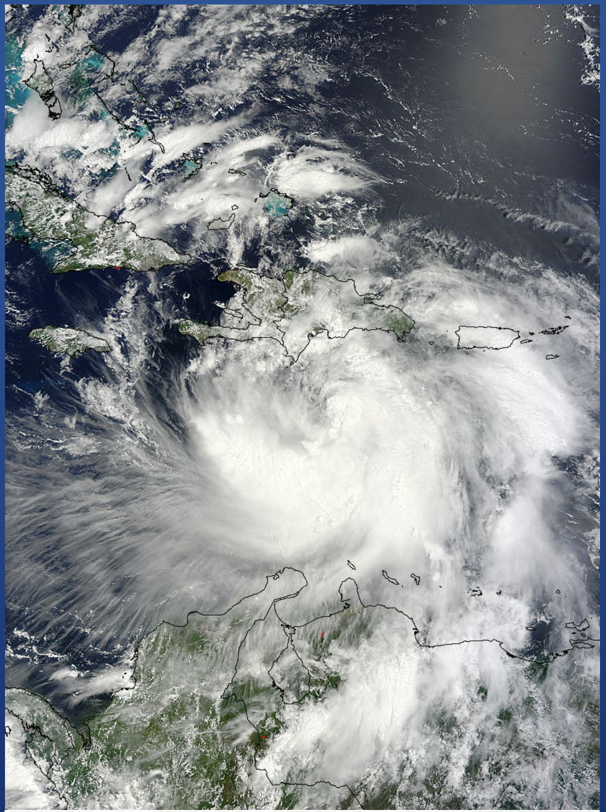
Fit the spiral parallel to the inner edge of the band (VIS) or to the coldest tops in the band (IR)

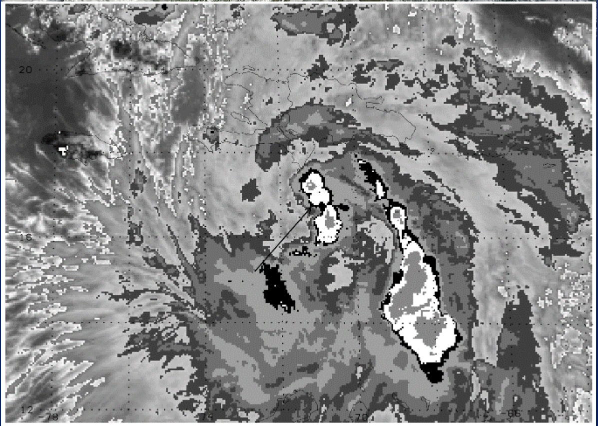
Measure only the primary band of the cyclone - other bands don't count

Endpoints of bands can be rather subjective

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

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

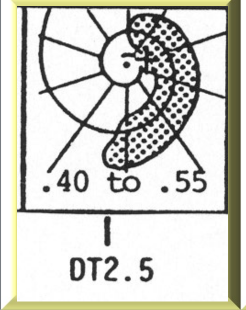
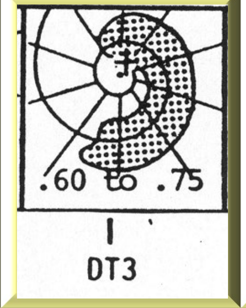
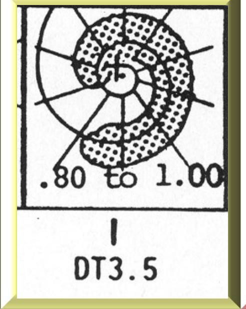
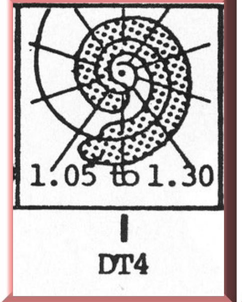
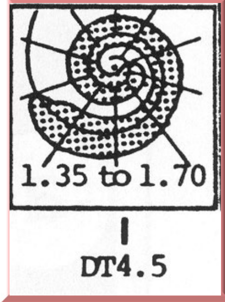




TROPICAL CYCLONE ANALYSIS WORKSHEET

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 (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 2A - Curved Band Patterns

Flow chart images						
Spiral arc distance (tenths along log 10º 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 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).

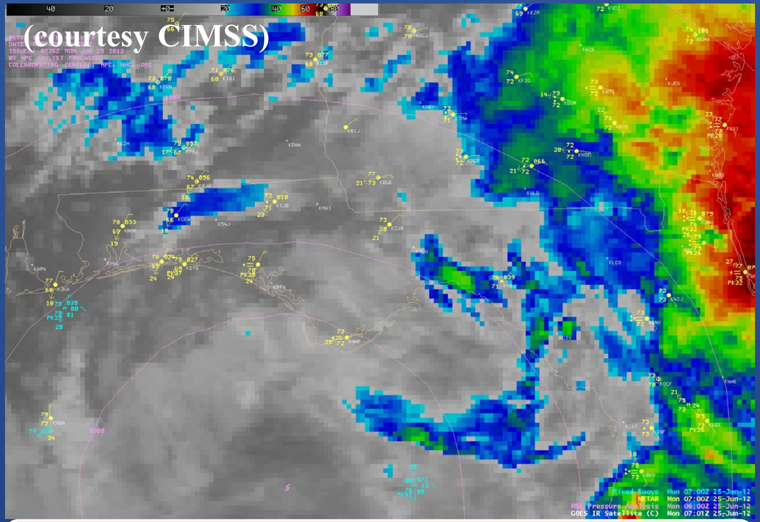
The edge of the convection can be rather subjective.

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*.

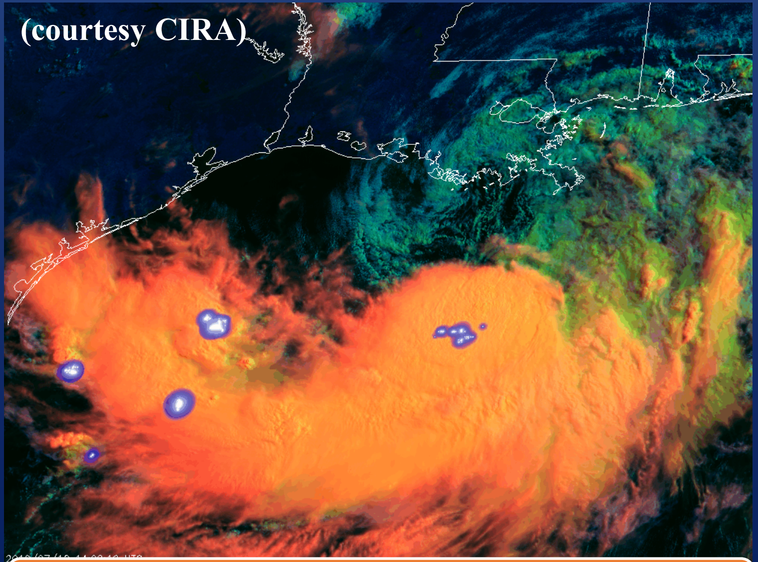
Shear pattern convection can dissipate between pulses/bursts to the point where a DT cannot be determined. The Pattern-T or Model Expected-T can be used to classify such systems.

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

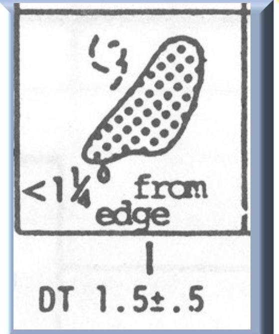
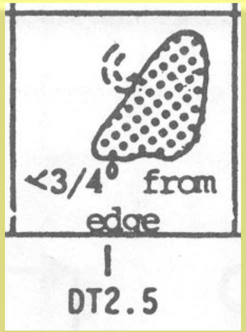
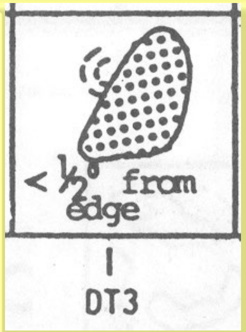
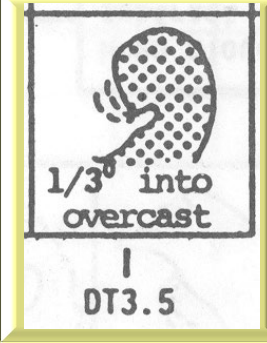
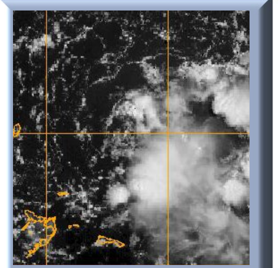
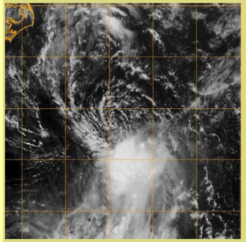
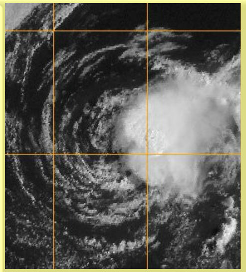
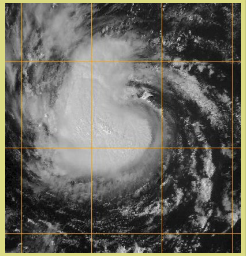


Debby (2012) convective burst



Barry (2019) Cloud Phase RGB

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 2C – Measuring Eye Patterns
Some Assembly Required!

Find the eye number (E-number).

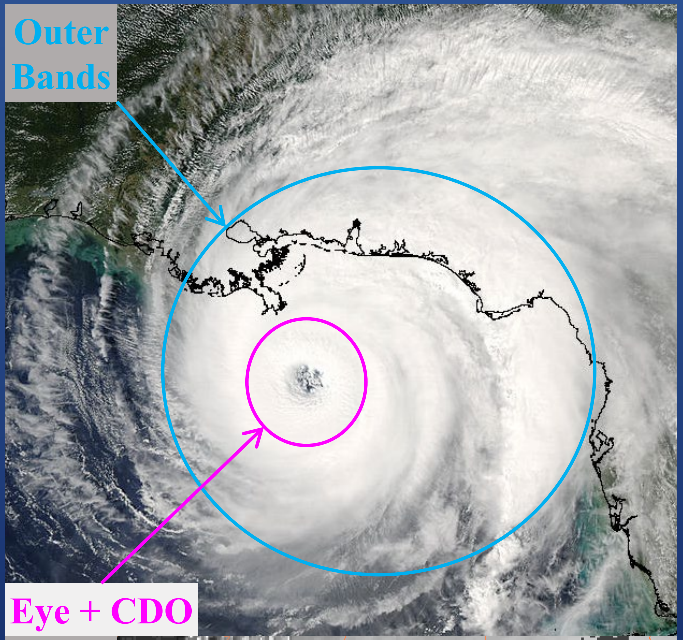
Perform an Eye Adjustment.

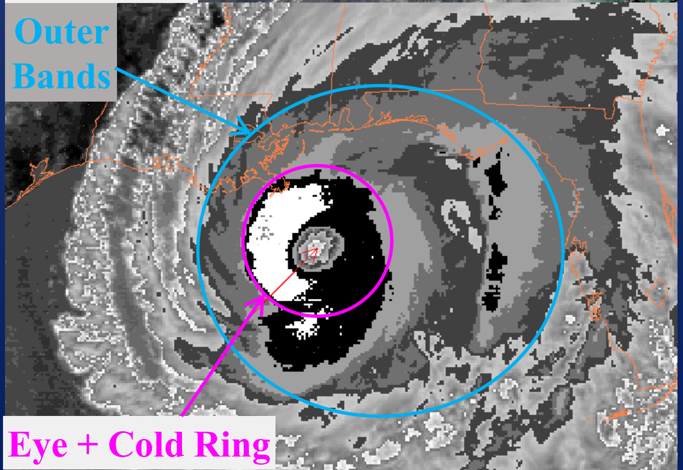
Create the Central Feature (CF) number from the E-number and Eye Adjustment.

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



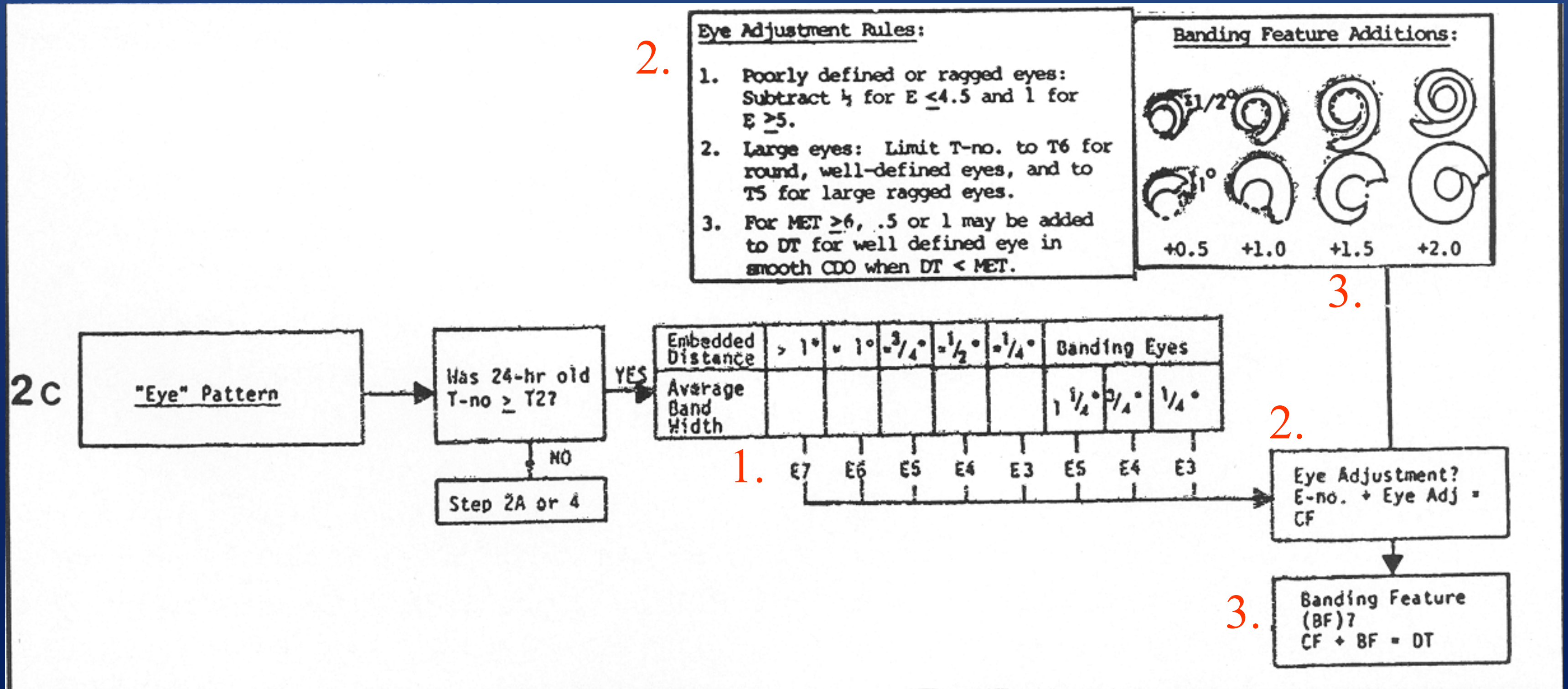


Step 2C - Visible Eye Patterns

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)



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

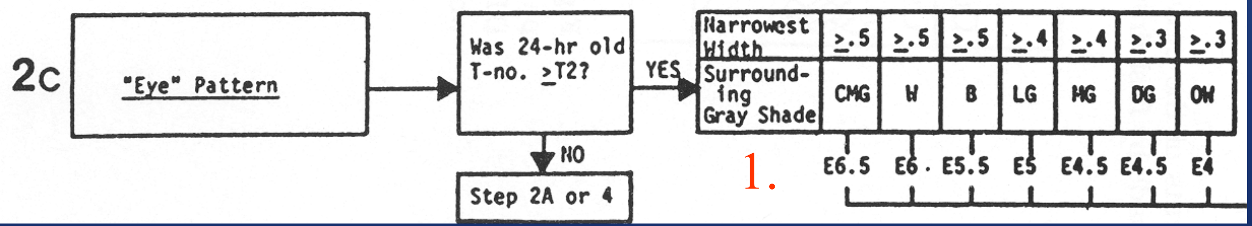
Note: You can interpolate between the eye numbers when appropriate!

Step 2C - 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)



2.

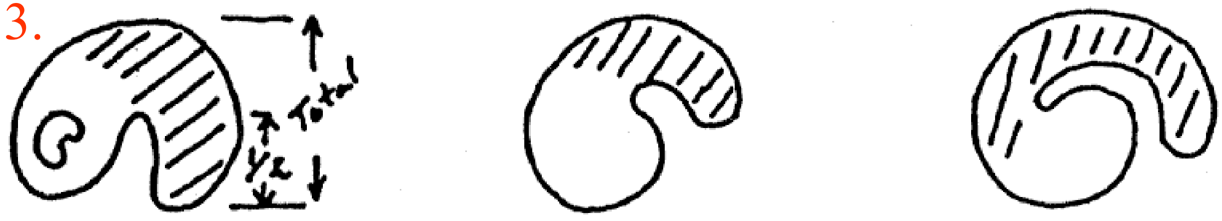
GRAY SHADE CODE (BD CURVE)

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

EYE TEMPERATURE

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

3.



a. Add 1/2 no.

b. Add 1/2 no.

c. Add 1 no.

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:

Surr. BD Color \ Eye Temperature	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

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

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

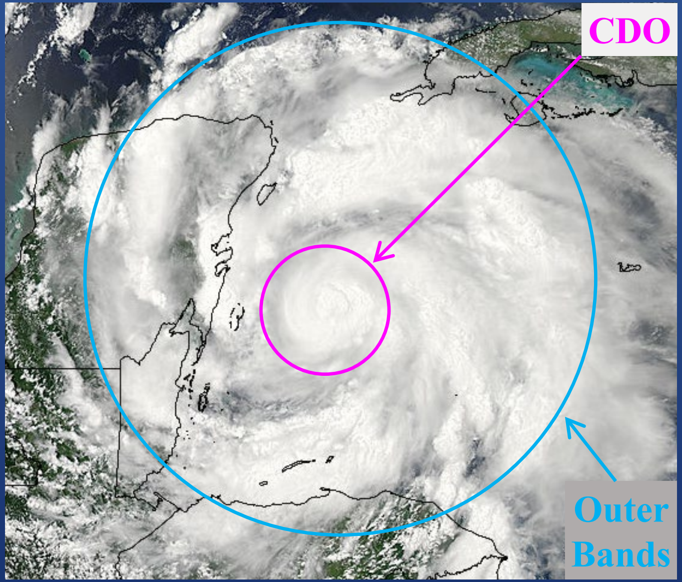
Both patterns directly produce <u>CF</u> numbers.

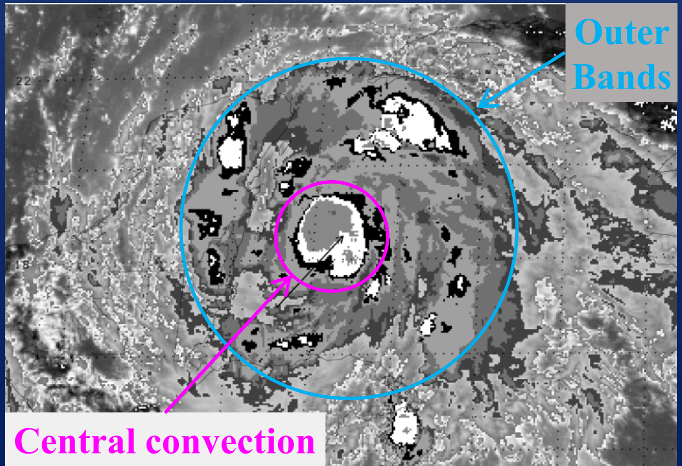
CDO pattern measures the size of the CDO.

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

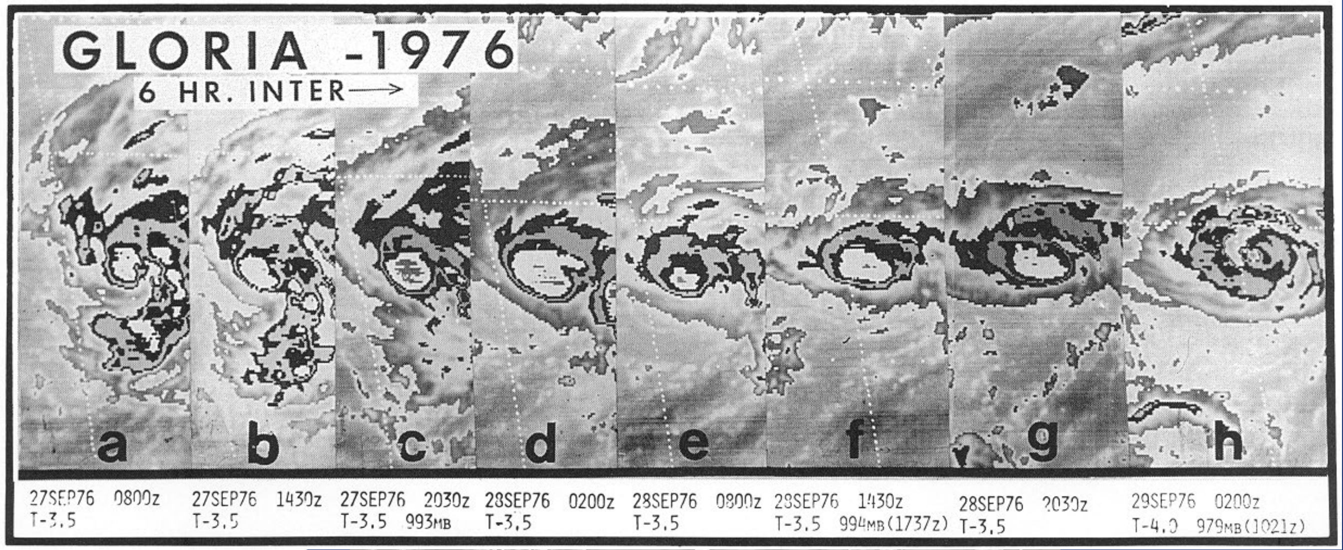
Step 2E - Is the 12 hour old FT ≥ 3.5? If not, go to step 2A or step 4.

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 3 - Central Cold Cover Pattern

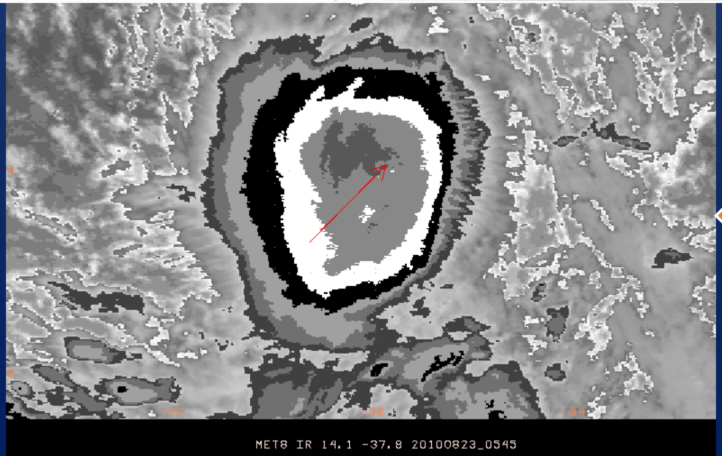
Central Cold (Dense) Cover Pattern

Rules: When past T-no. £ T3, maintain model trend for 12 hours; then hold same. When past T-no ³ 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)

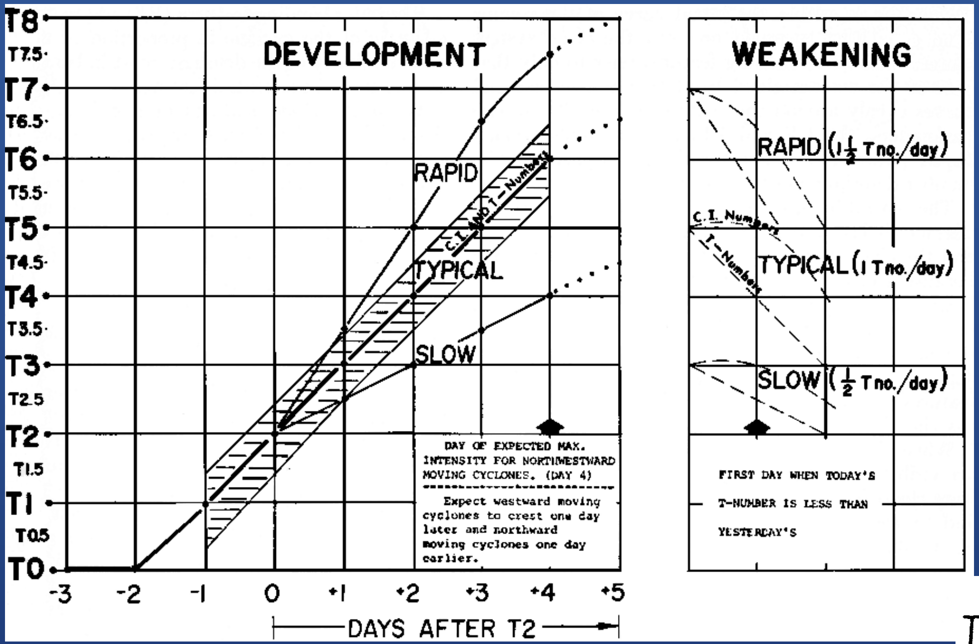
The Dvorak Technique employs a conceptual model of TC growth and decay rates over 24-h periods to help filter the diurnal convective variations observed in TC cloud patterns.

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.

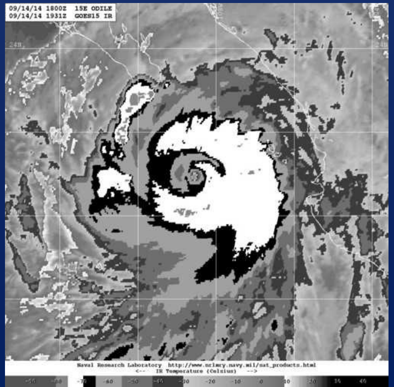
T-Number Estimates from Model and DT Constraints							
3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D -Developing W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

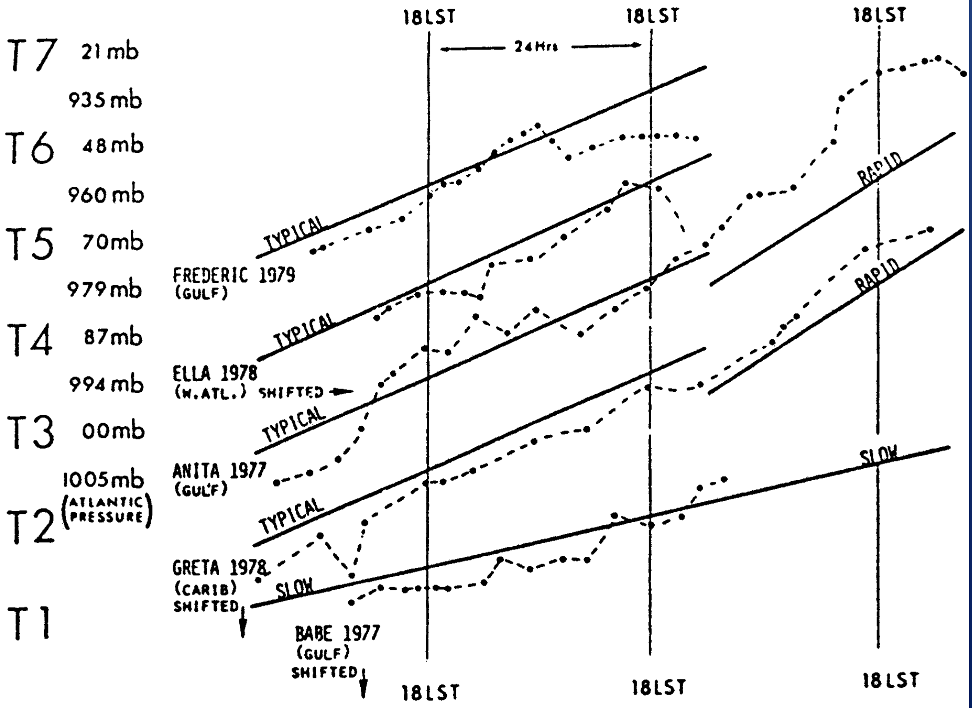
Dvorak Model Development Curves



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 <u>not</u> 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	

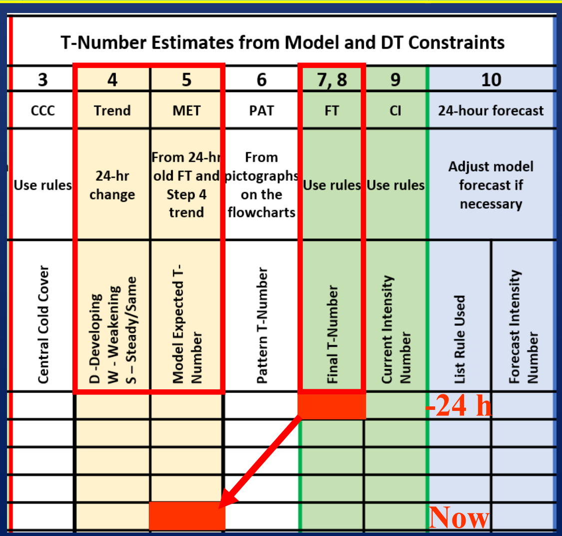
Step 5 - Model Expected T-Number

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



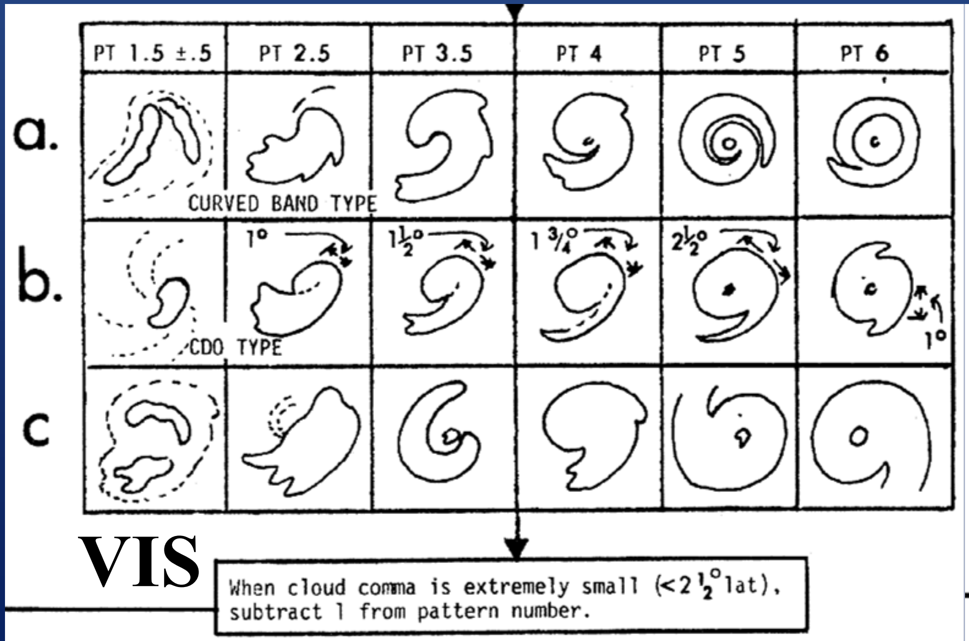
Step 6 - Pattern T-Number (PT or PAT)

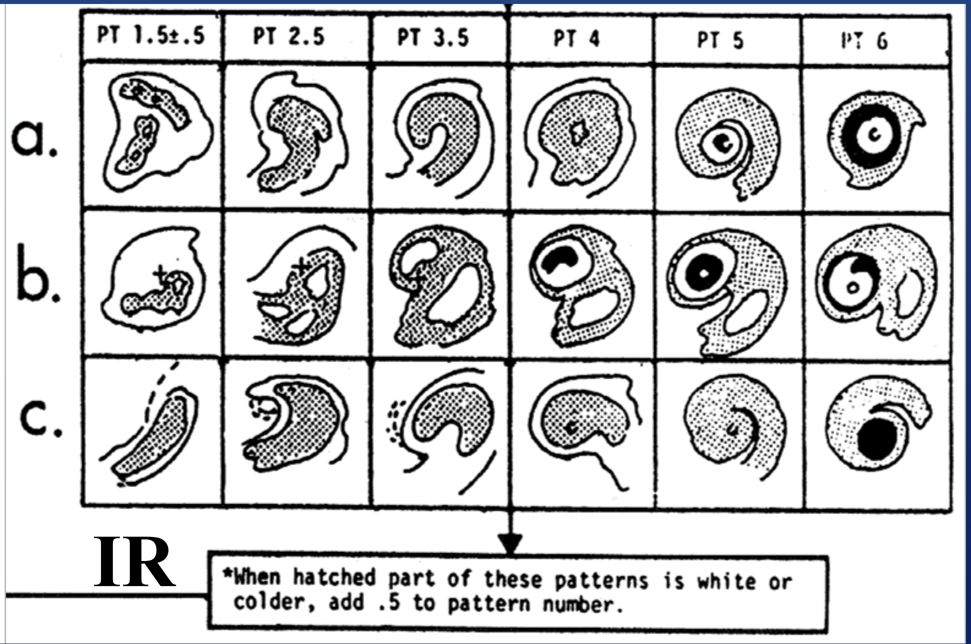
Choose the Pattern T-number by comparing the cyclone cloud pattern to the diagrams on the flow charts

PATs above T6 require extrapolation!

T-Number Estimates from Model and DT Constraints

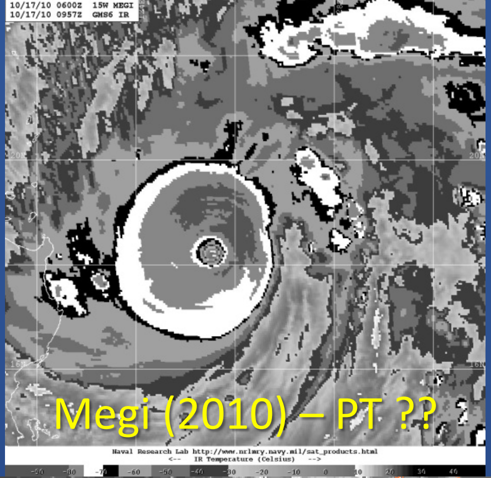
3	4	5	6	7, 8	9	10	
CCC	Trend	MET	PAT	FT	CI	24-hour forecast	
Use rules	24-hr change	From 24-hr old FT and Step 4 trend	From pictographs on the flowcharts	Use rules	Use rules	Adjust model forecast if necessary	
Central Cold Cover	D - Developing W - Weakening S – Steady/Same	Model Expected T-Number	Pattern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

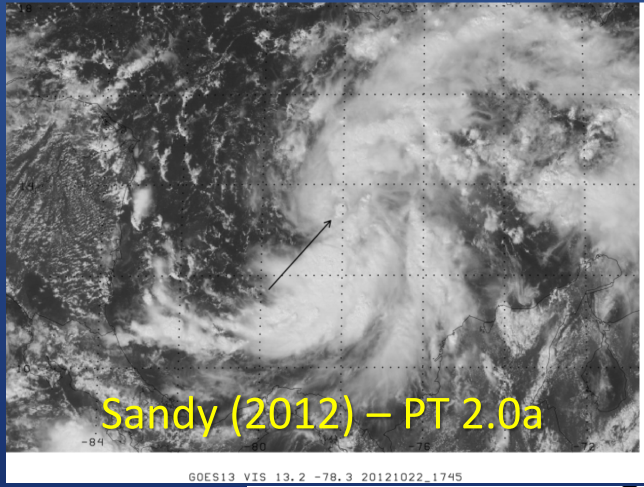


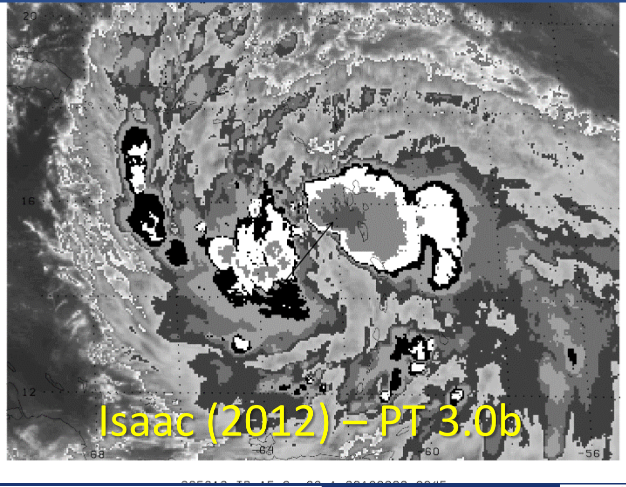


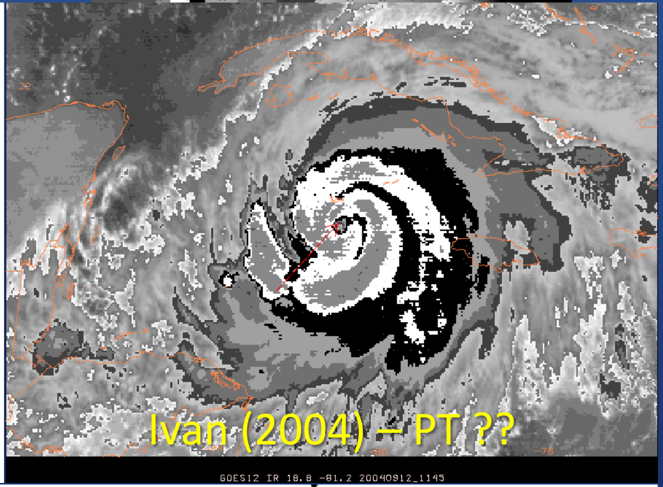
If the PT is 1 or more T-numbers from the MET, check your work!

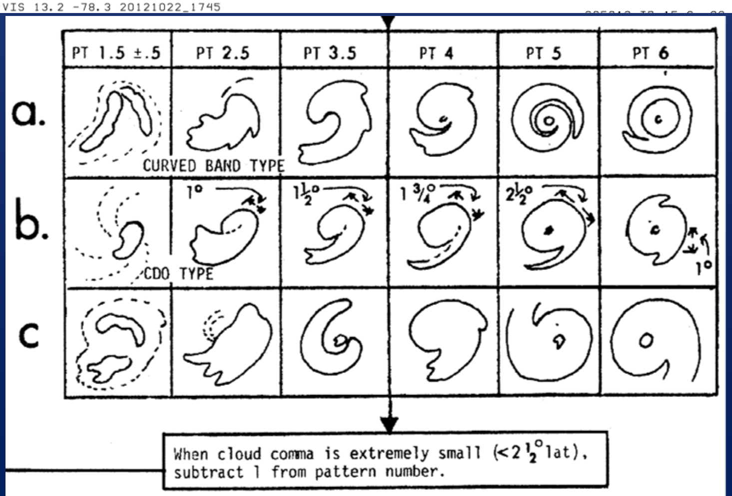
Step 6 - Pattern T-Number (PT or PAT)

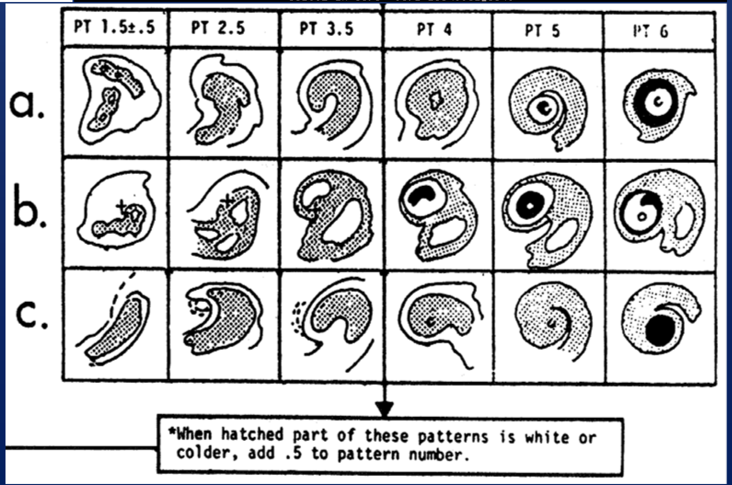












Step 7 - Final T-Number (FT)

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 <u>and</u> 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 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

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

Step 8 - FT Number Change Limits

For <u>early</u> development: 0.5 T-numbers over 6 h

Original FT Constraints for storms with T≥4.0 (Dvorak):	Modified FT Constraints now used for developing storms above T1.5 (24 h or more after the initial T1) (Pike NHC study):
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)	

These are the <u>maximum</u> 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 never 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

Why are there constraints on the FT and CI?

Weak systems sometimes lose all convection during the diurnal minimum.

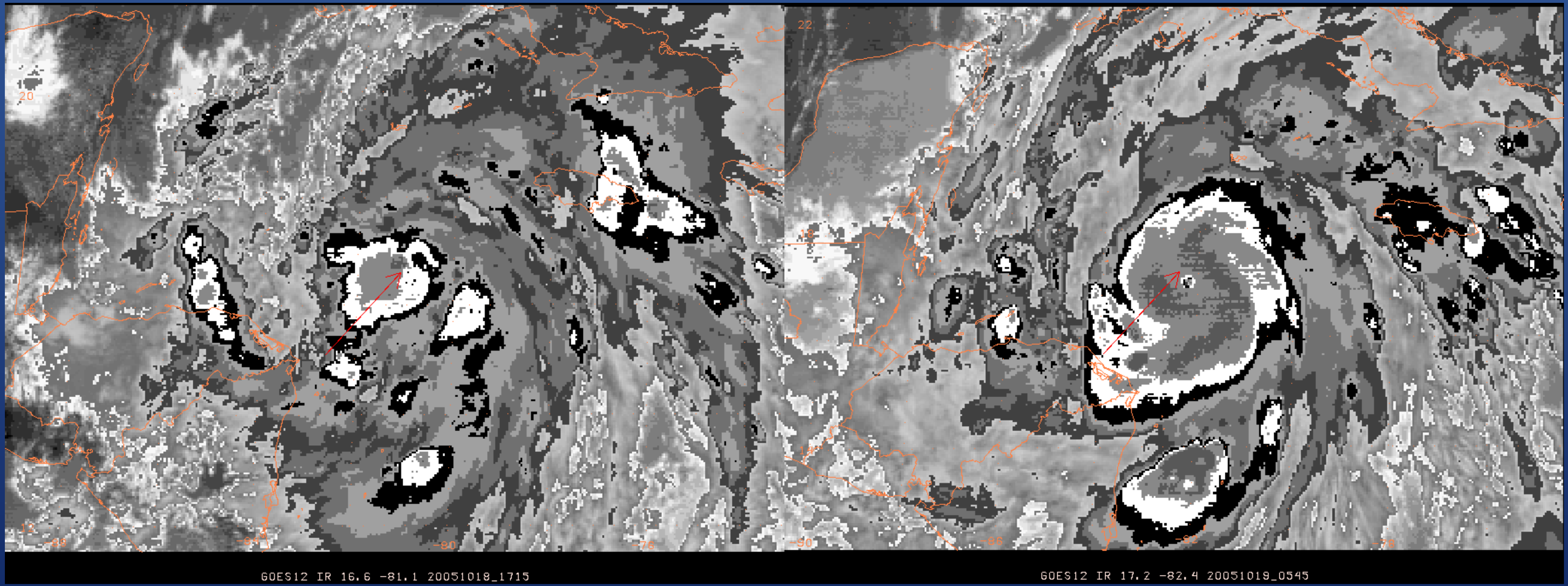
Cloud patterns for weak systems sometimes look unrealistically strong.

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!

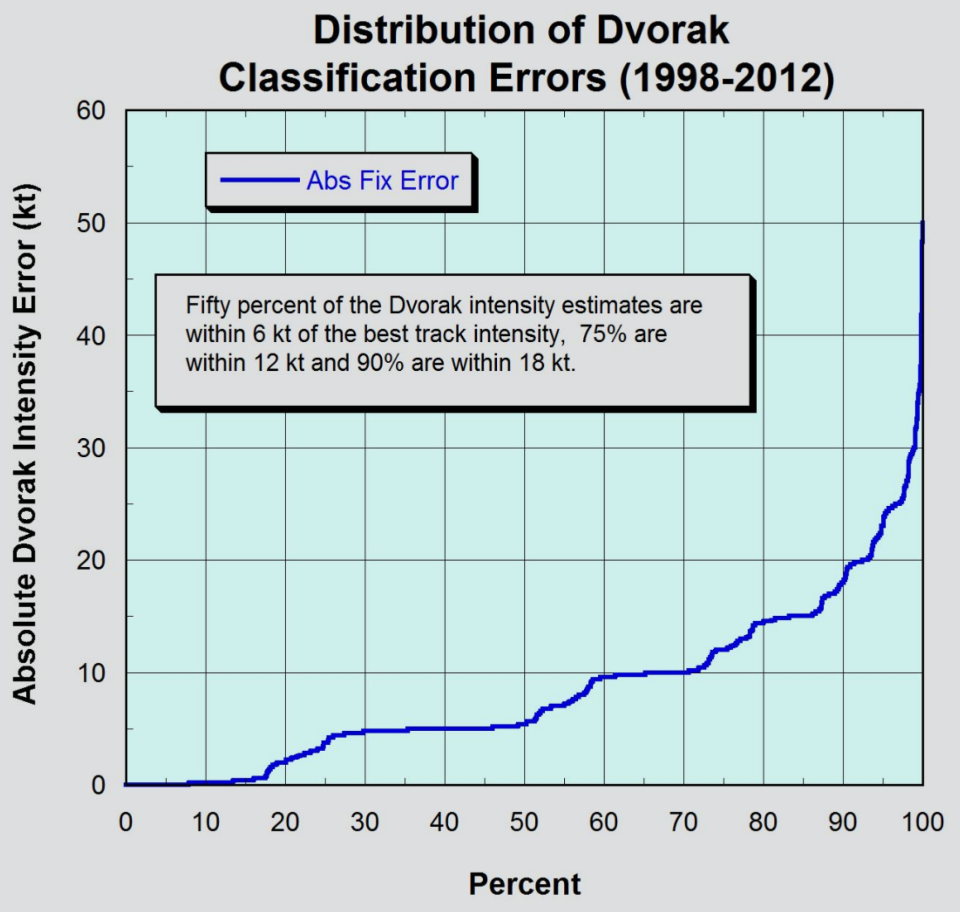
Hurricane Wilma (2005)

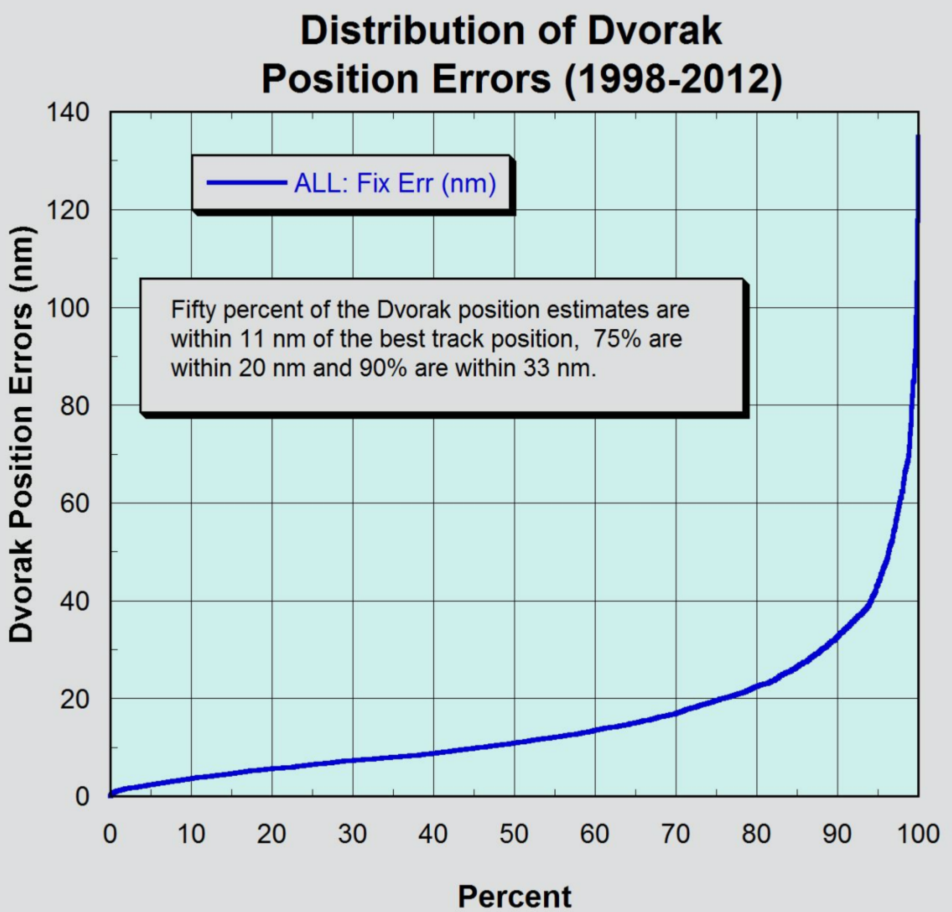


75 kt/975 mb (Images ~12 h apart) 150 kt/892 mb

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

Dvorak Error Distribution





Images courtesy of Brown and Franklin

What trend in TC intensity is representative of the following FT/CI number sequences?

0

Rapid Development 0%

Normal development 0%

Rapid Weakening 0%

Normal Weakening 0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

Date	Time	FT/CI
9/12	00 UTC	1.5/1.5
9/12	06 UTC	2.0/2.0
9/12	12 UTC	2.5/2.5
9/12	18 UTC	3.0/3.0
9/13	00 UTC	3.5/3.5
9/13	06 UTC	4.0/4.0
9/13	12 UTC	4.5/4.5

What trend in TC intensity is representative of the following FT/CI number sequences?

0

Normal weakening 0%

Steady intensity 0%

Weakening, then re-development 0%

Normal development 0%

Date	Time	FT/CI
9/12	00 UTC	5.5/5.5
9/12	06 UTC	5.0/5.5
9/12	12 UTC	4.5/5.5
9/12	18 UTC	3.5/4.5
9/13	00 UTC	4.0/4.5
9/13	06 UTC	4.5/4.5
9/13	12 UTC	5.0/5.0

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							
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

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