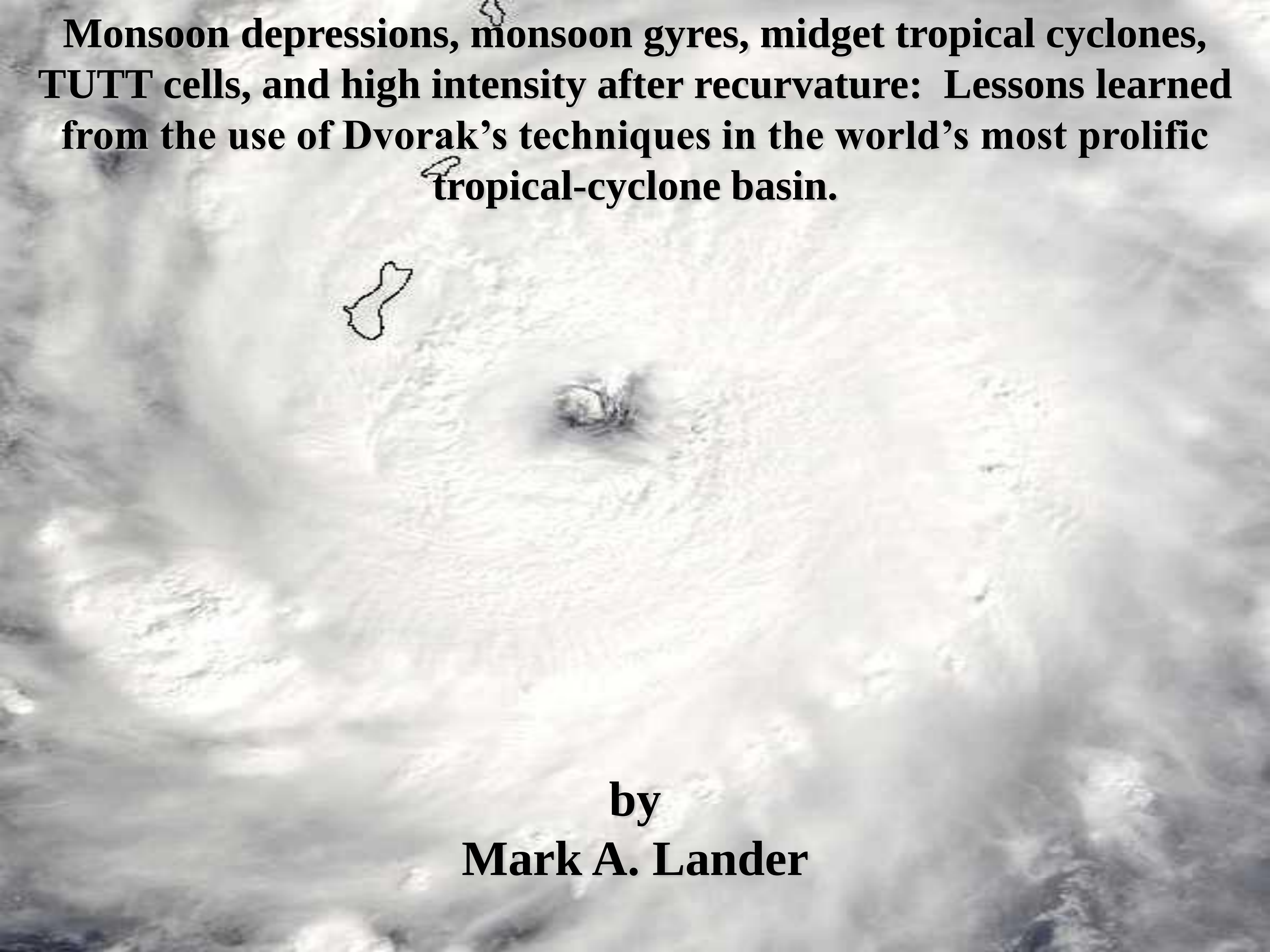
Monsoon depressions, monsoon gyres, midget tropical cyclones, TUTT cells, and high intensity after recurvature: Lessons learned from the use of Dvorak's techniques in the world's most prolific tropical-cyclone basin.



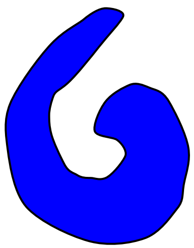
by

Mark A. Lander

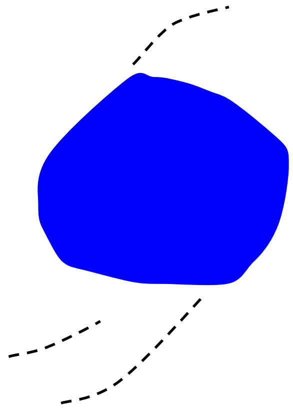
VERN DVORAK

Dvorak (1972, 1975, 1984) made revolutionary advances in using satellite imagery to detect tropical cyclones and to estimate their intensity. Dvorak observed that it was the pattern formed by the clouds that is related to the cyclone's intensity and not the amount of clouds in the pattern. He made the further observation that most tropical cyclones exhibit cloud patterns of the curved-band pattern type through much of their life times.

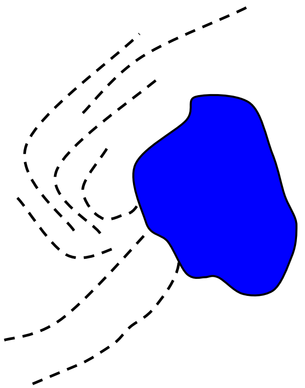
DVORAK TC PATTERNS



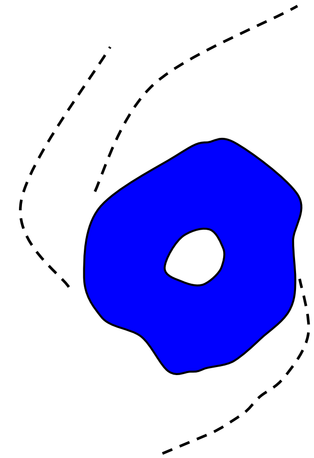
1. Curved band



2. Central Dense Overcast (VIS)
Embedded Center (EIR)

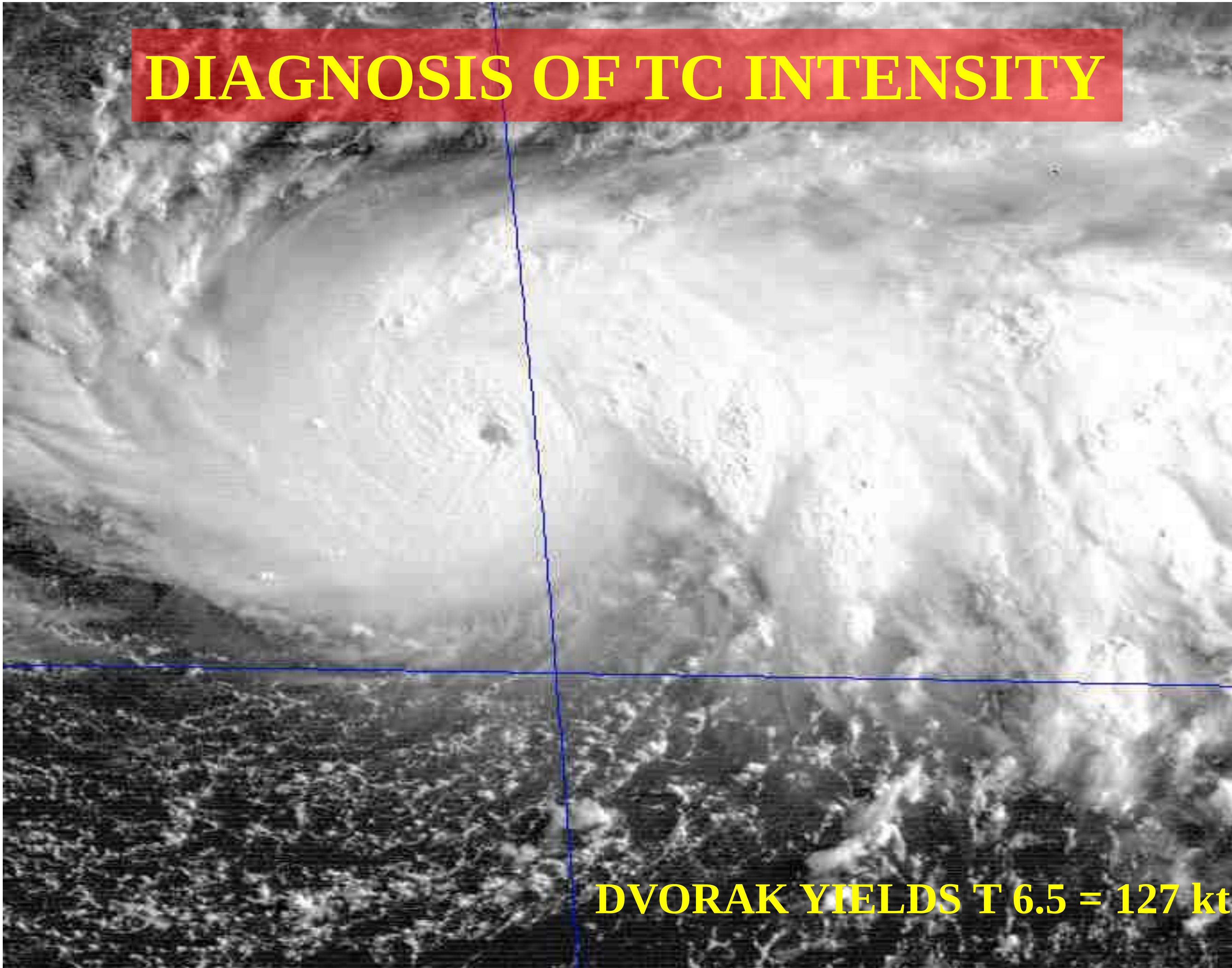


3. Shear



4. Eye

DIAGNOSIS OF TC INTENSITY



DVORAK YIELDS T 6.5 = 127 kt

TC INTENSITY DIAGNOSIS

DVORAK (1975) VIS TECHNIQUES 2-5a

DVORAK (1984) EIR TECHNIQUES 2-4b

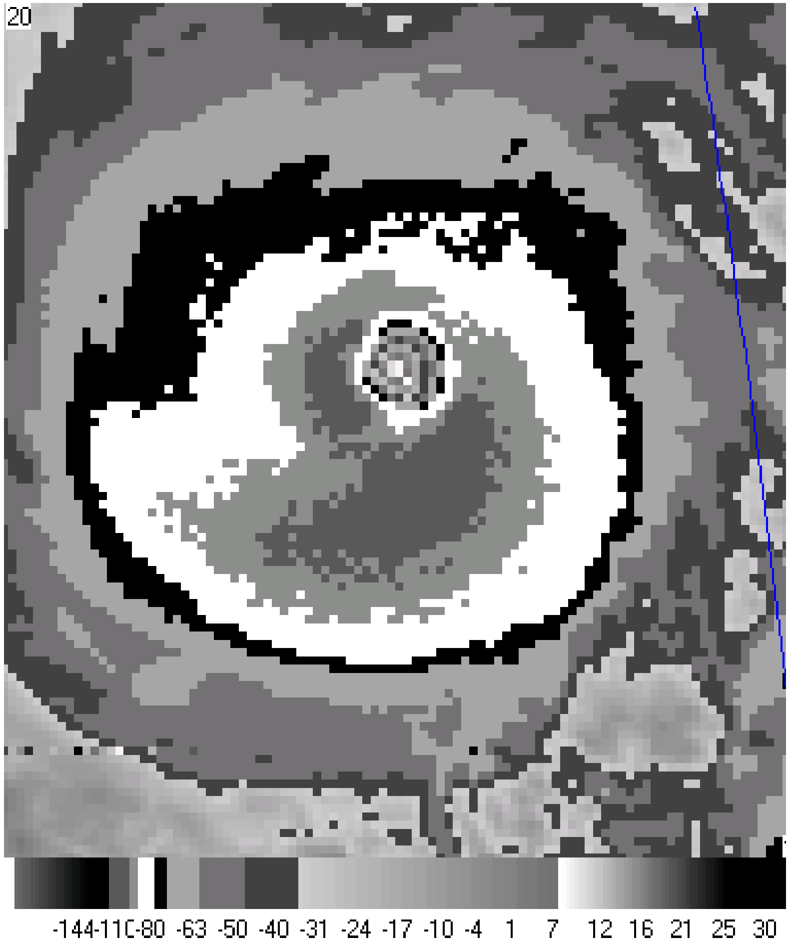
accuracy: 5-7 $m\ s^{-1}$

Good for the past 30 yrs

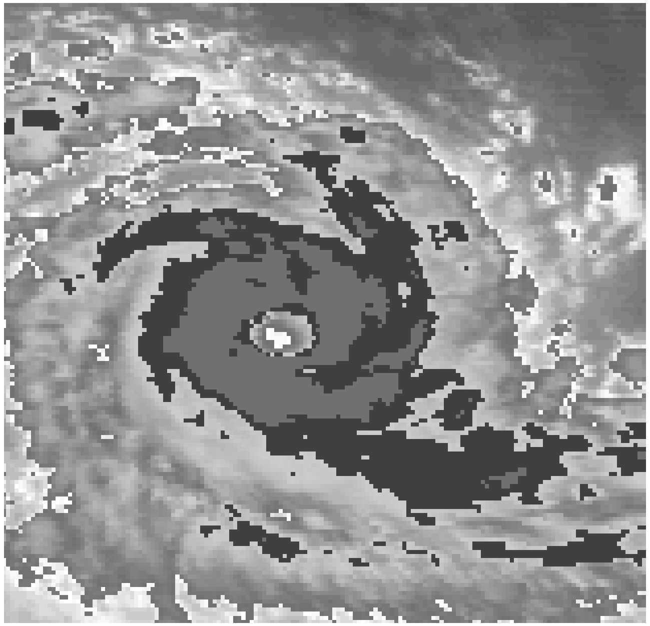
DVORAK ANALYSIS YIELDS 24-HR FORECAST !!!!

GRAY SHADE CODE (BD CURVE)

WMG (Warm Mediun 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 C
CDG (Cold Dark Gray) ≤ -81 C



TYPHOON PODUL



HURRICANE CATARINA

INTENSITY FORECASTING

FROM DVORAK:

-TC's intensify at an average rate of 1 "T Number" per day.

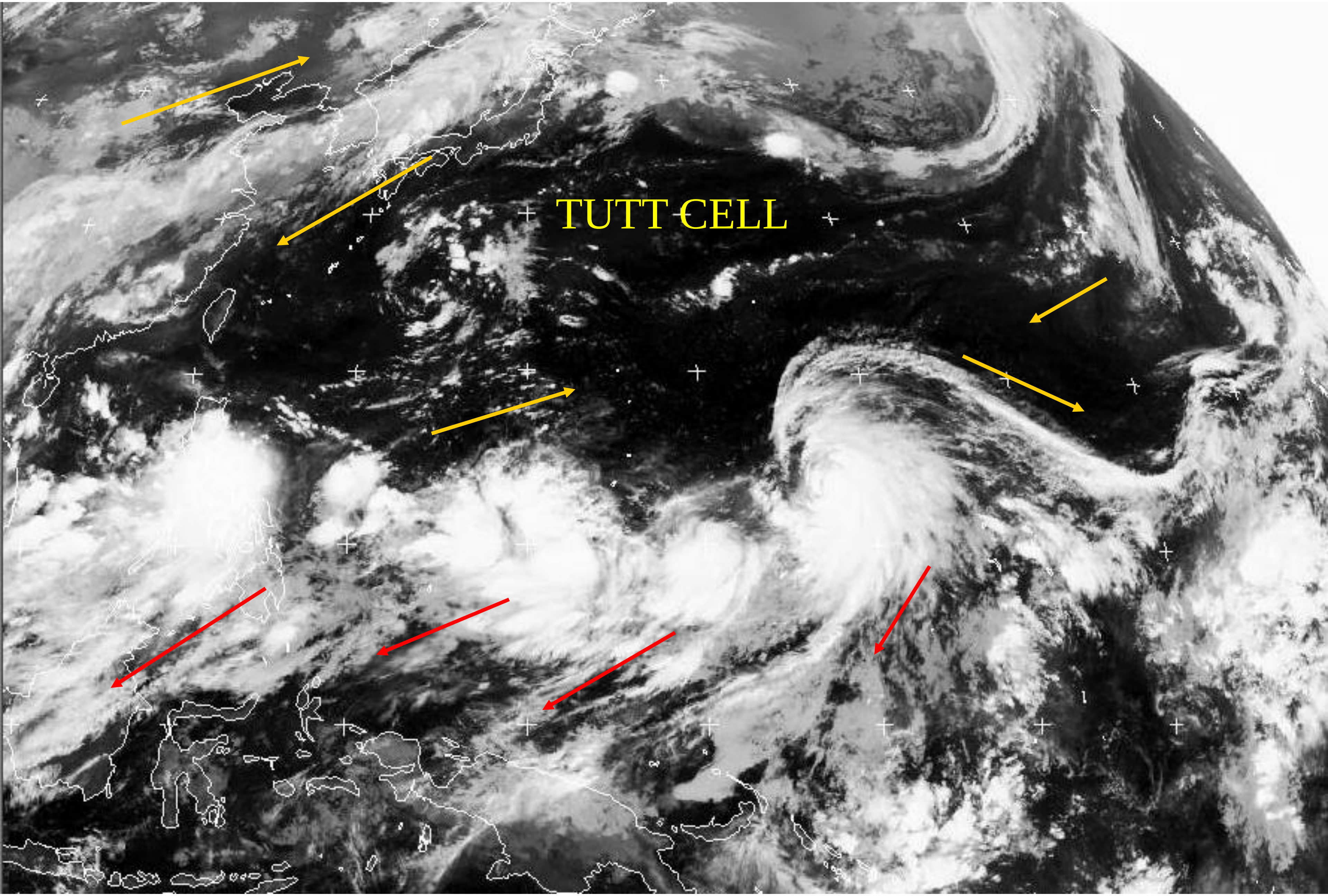
-Fast Intensification – 1.5 T Number per day.

-Slow Intensification – 0.5 T Number per day.

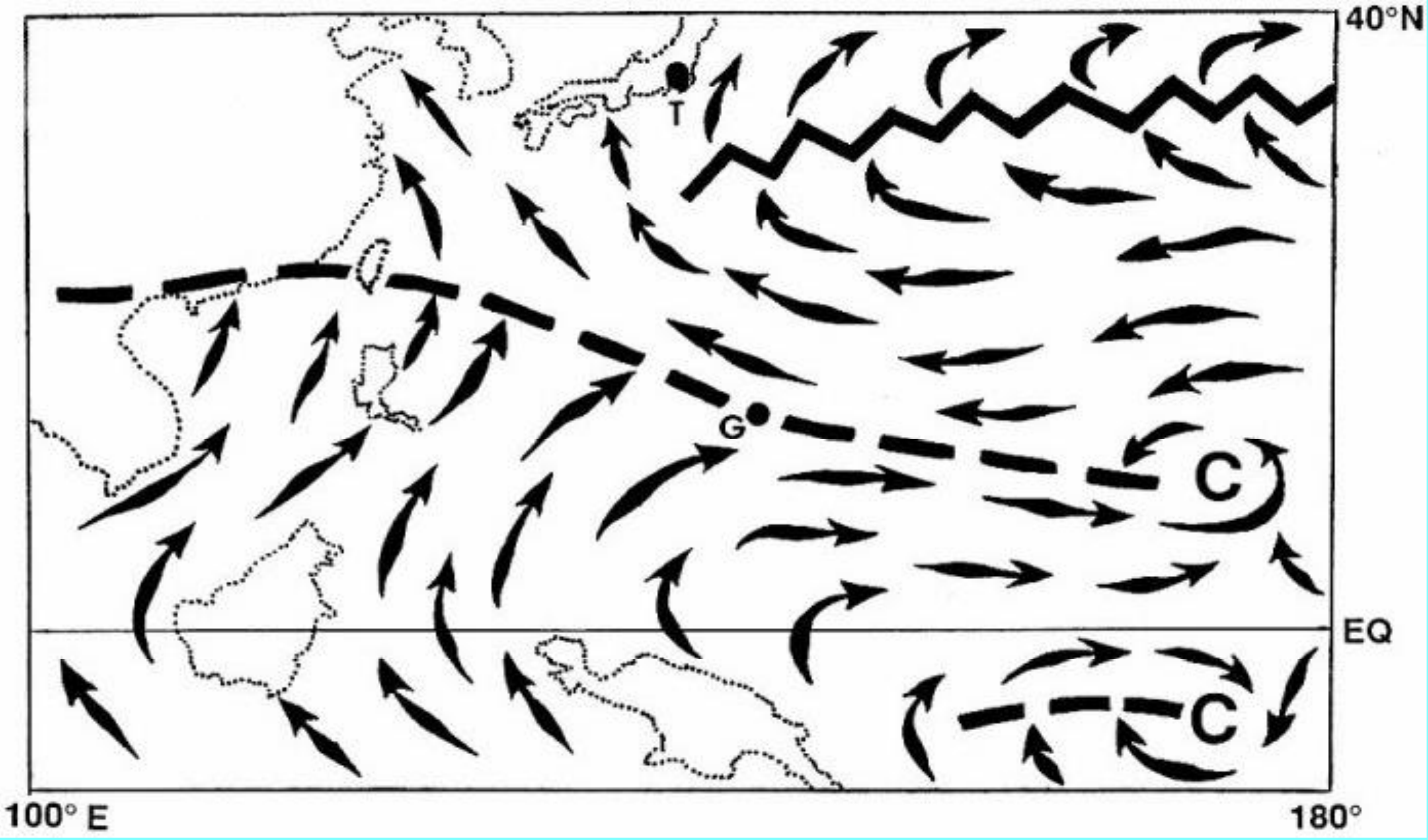
HARD TO BEAT THIS !!

DVORAK MEETS THE WESTERN PACIFIC

a) Monsoon Depressions
b) Subtropical Cyclones
c) Cold Tropopause
d) Extratropical Transition
e) Midget Tropical Cyclones

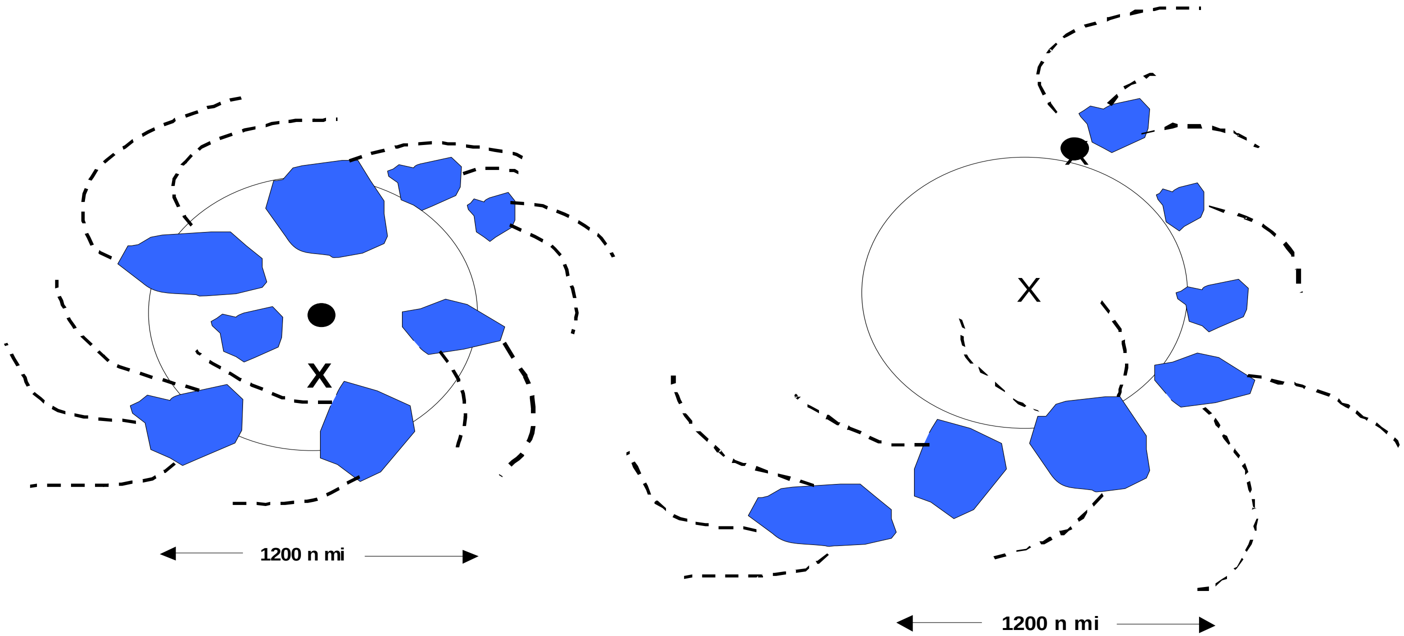

TUTT CELL

MONSOON!!!!



AUGUST 1997 MONTHLY MEAN FLOW

MONSOON DEPRESSIONS



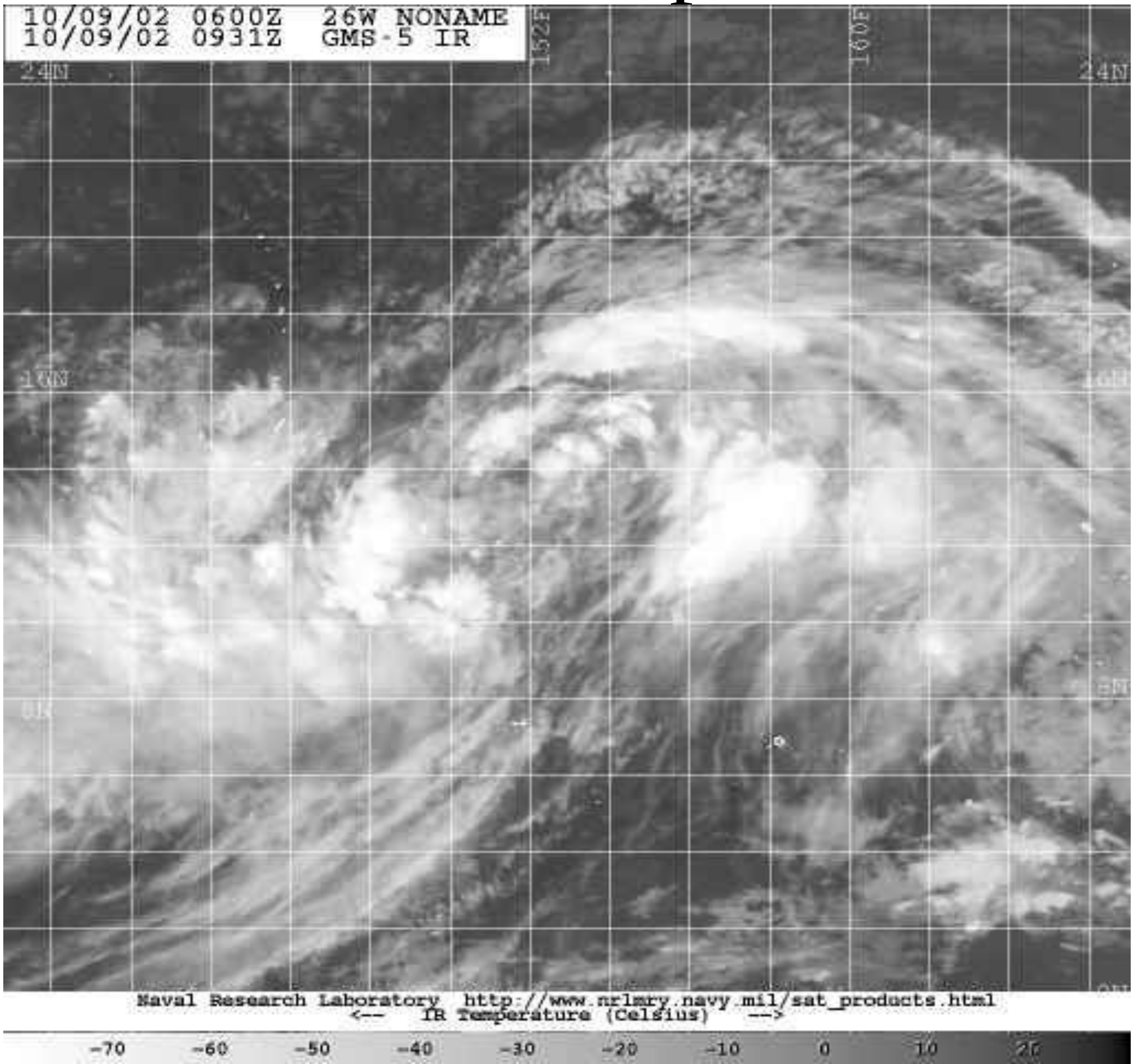
MONSOON DEPRESSION

MONSOON GYRE

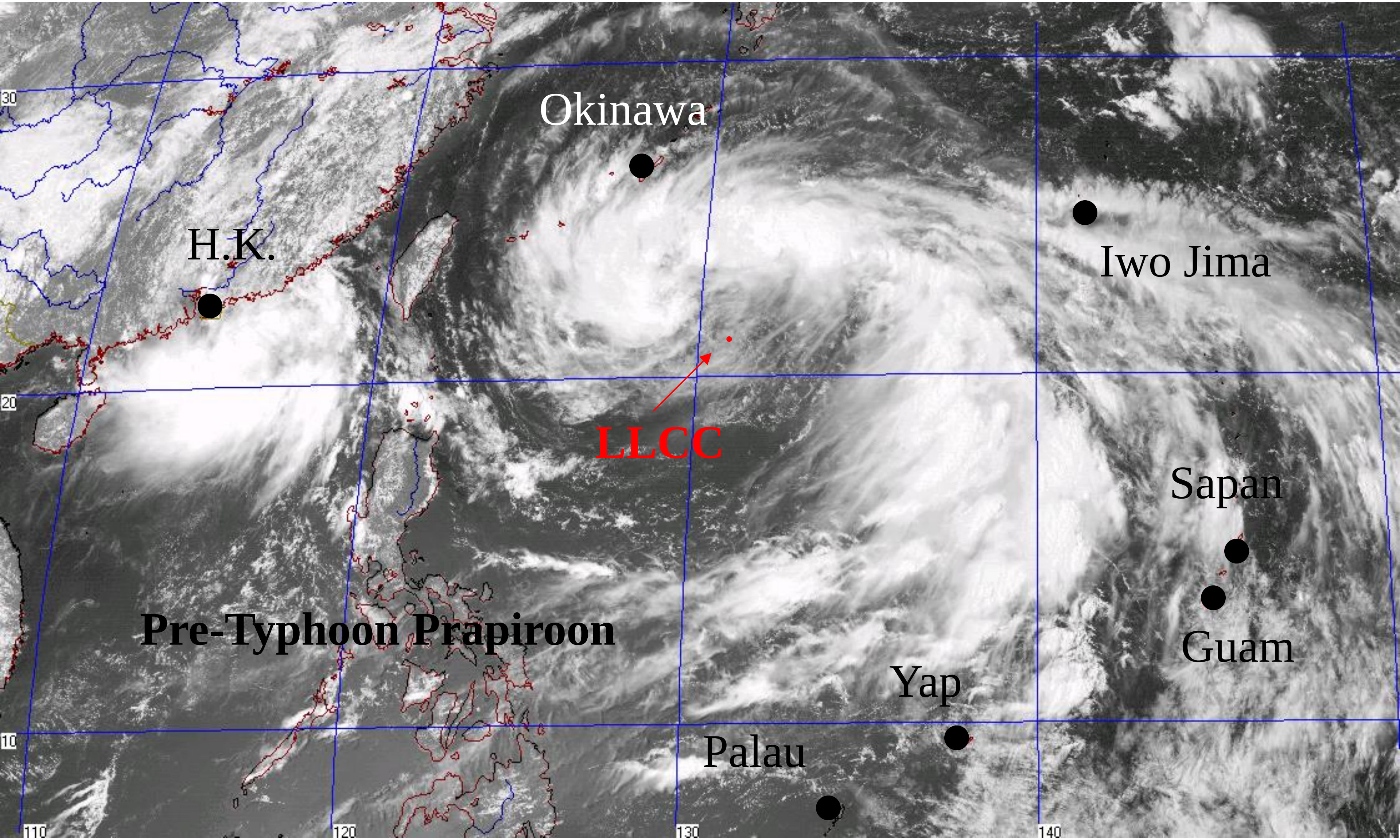
Other cyclonic circulations in the tropics do not fall into Dvorak's pattern types, including monsoon depressions (MD) (JTWC 1996) and monsoon gyres (MG) (Lander 1994).

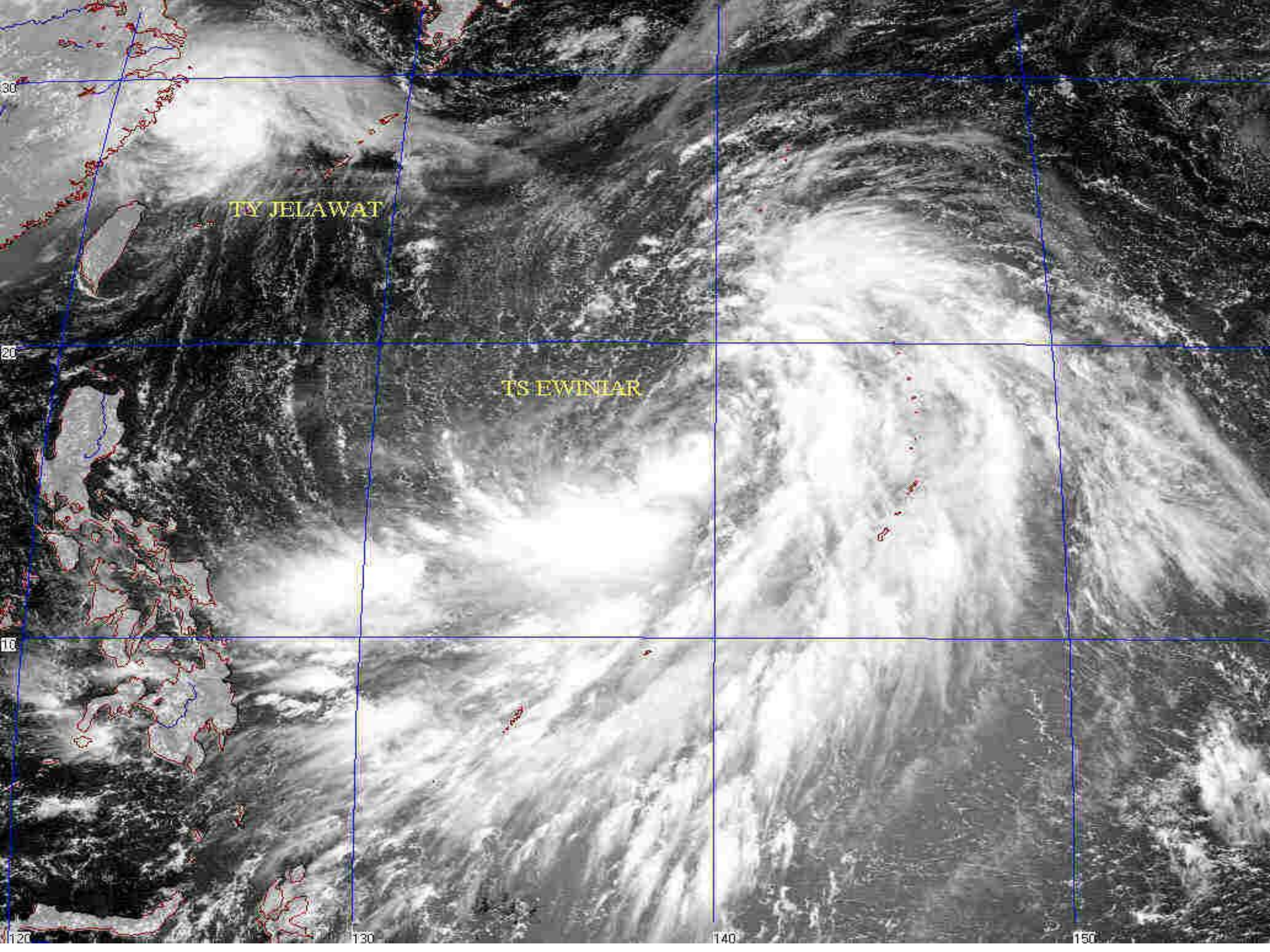
Some have argued that these types of cyclones are not tropical cyclones in the conventional sense as defined by Dvorak, and should not be numbered or named by Tropical Cyclone Warning Centers. The primary structural difference between these types of cyclones and conventional tropical cyclones is the larger displacement of the band of maximum surface winds from the center in the MD and MG, an incomplete ring of high winds in the MD and MG, and a much broader light-wind core in the MD and MG cyclones.

Monsoon Depression



MONSOON GYRE!!




TY JELAWAT
TS EWINIAR
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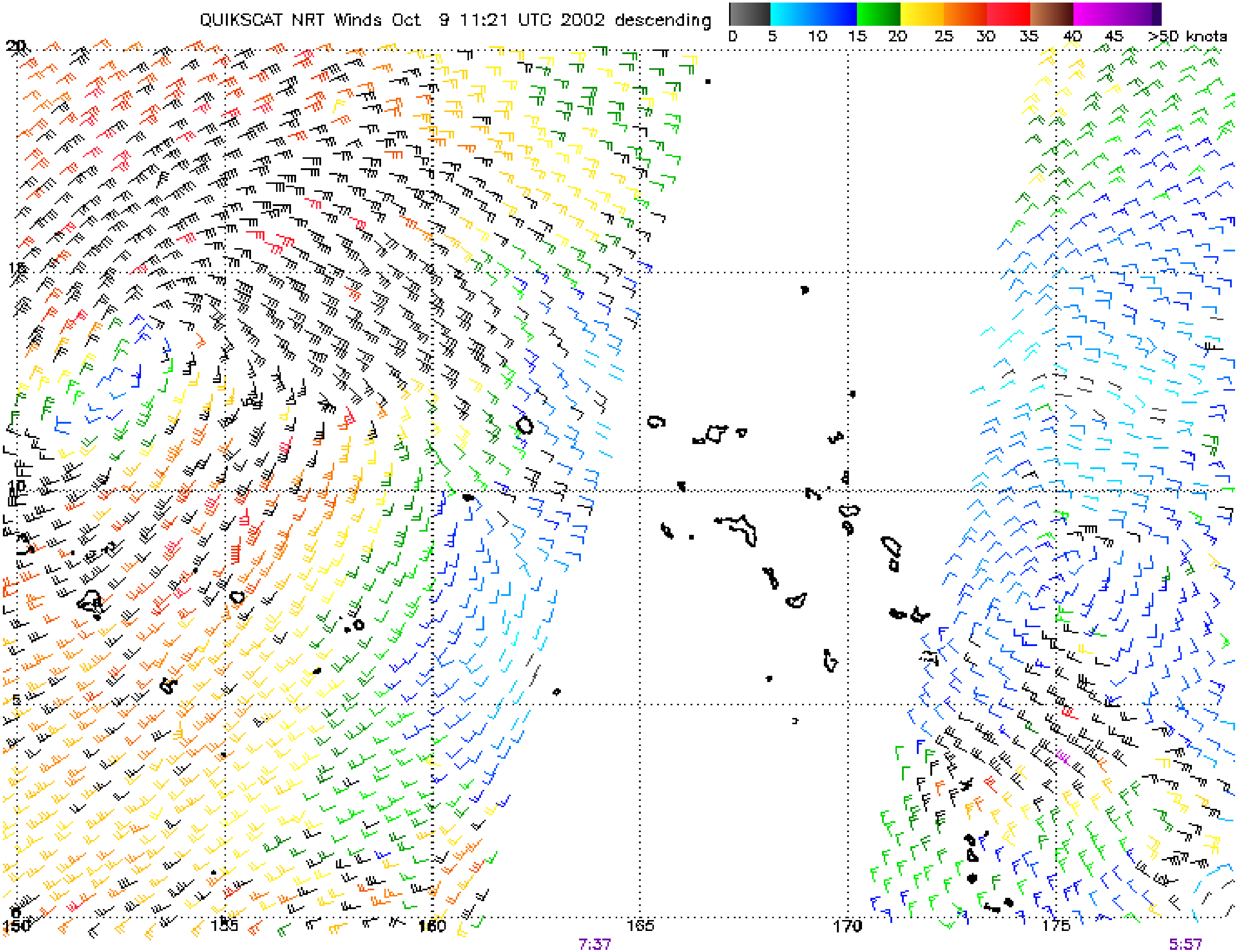
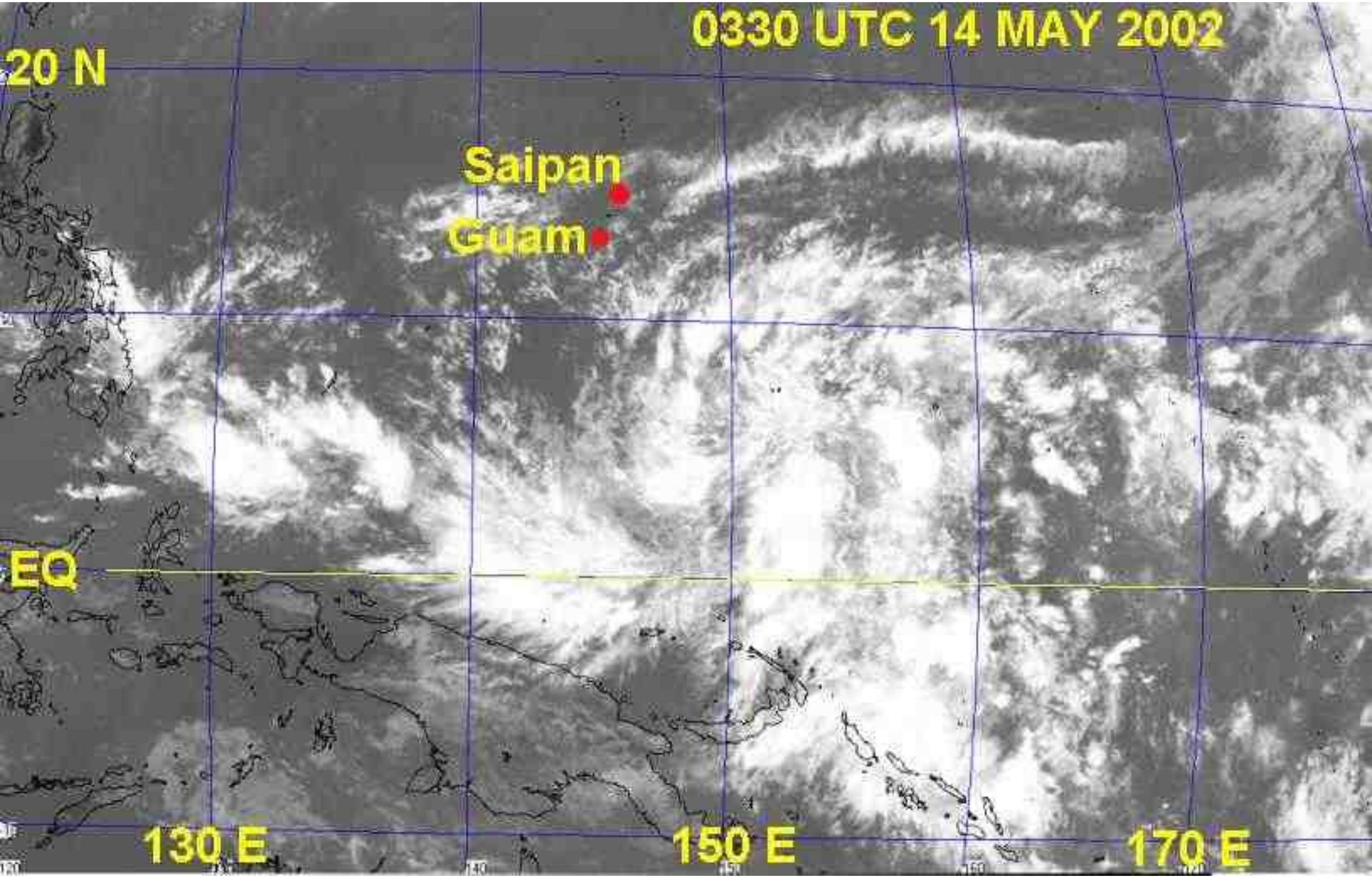
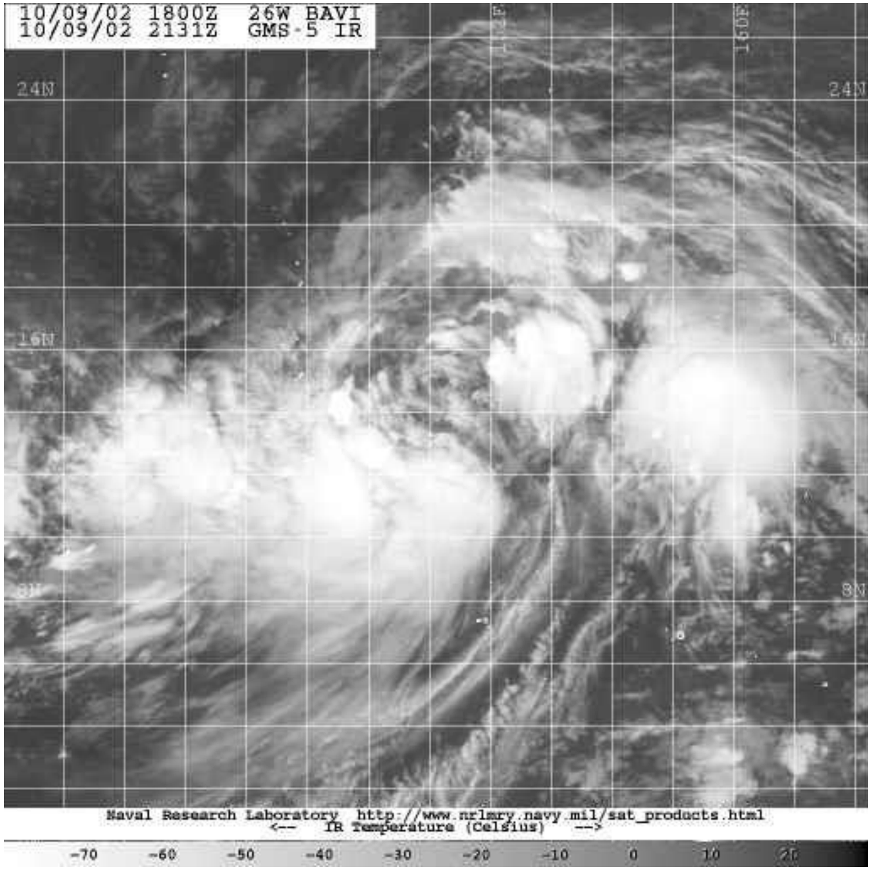


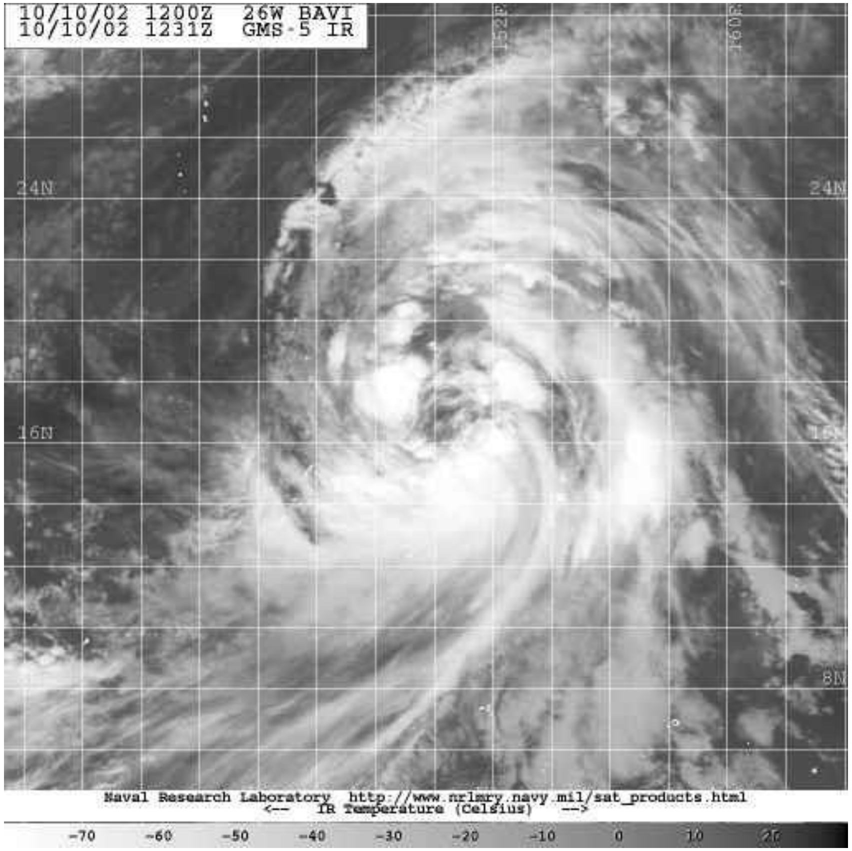
Note: 1) Times are GMT 2)Times correspond to 10N at right swath edge – time is right swath for overlapping swaths at 10N
3)Data buffer is Oct 9 11:21 UTC 2002–22 hrs 4)Black barbs indicate possible rain contamination
NOAA/NESDIS/Office of Research and Applications


0330 UTC 14 MAY 2002
20 N
Saipan
Guam
EQ
130 E
150 E
170 E

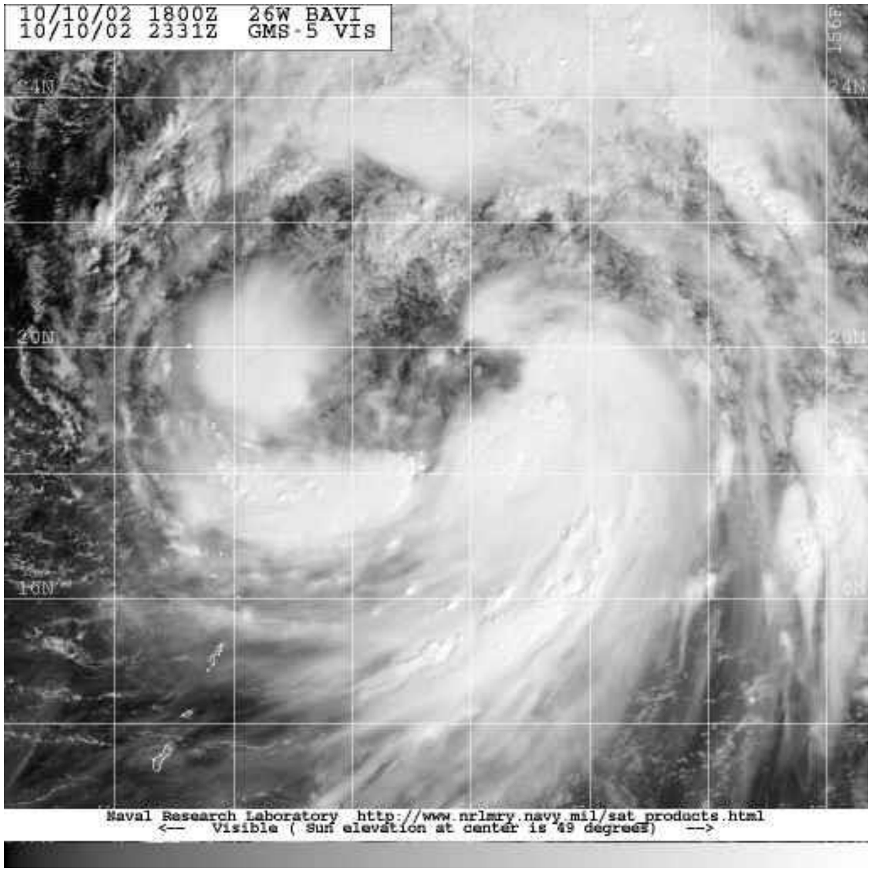
09 OCT 1200 UTC

10 OCT 1200 UTC

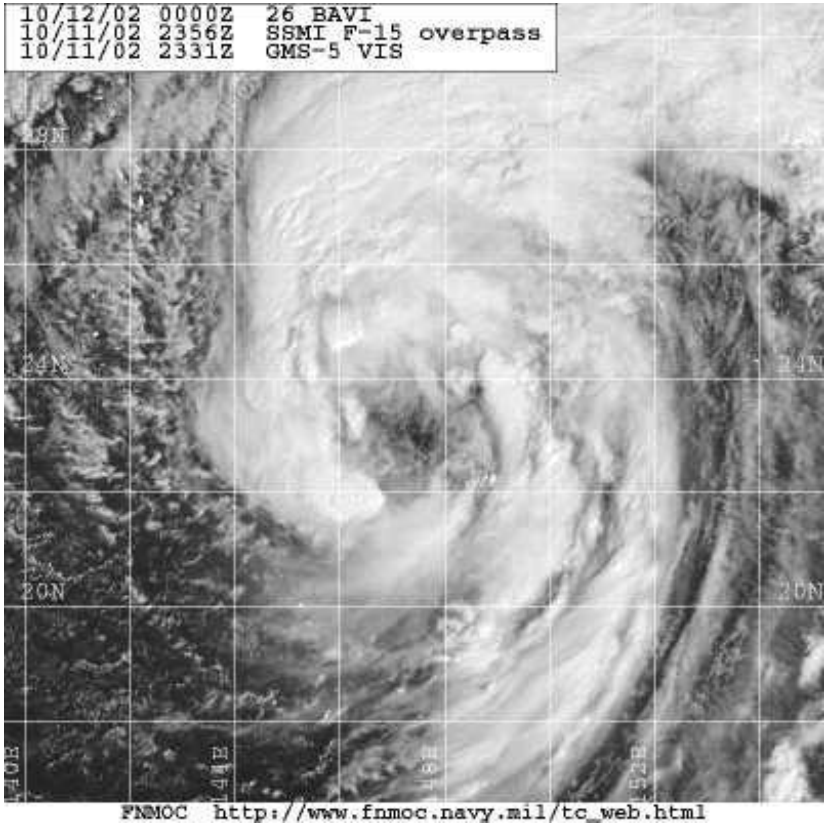




10 OCT 2330Z



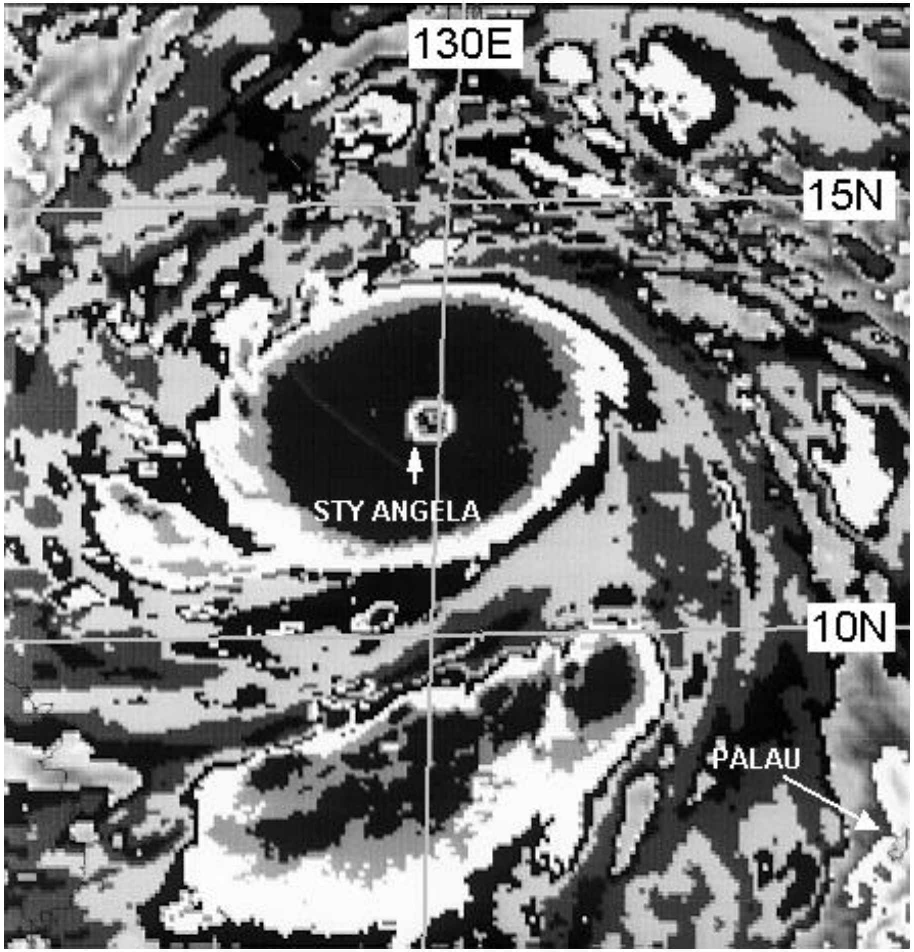
11 OCT 2330Z



MONSOON DEPRESSIONS

- No Persistent Central Convection (at First)
- When Does it Become a Conventional TC?
- Instant TS Cases!
- T Numbers Too Low (at First) (Hard to catch up!)

COLD TROPOPAUSE



DVORAK RULES FOR EIR IMAGERY

1. START
Locate cloud system center.

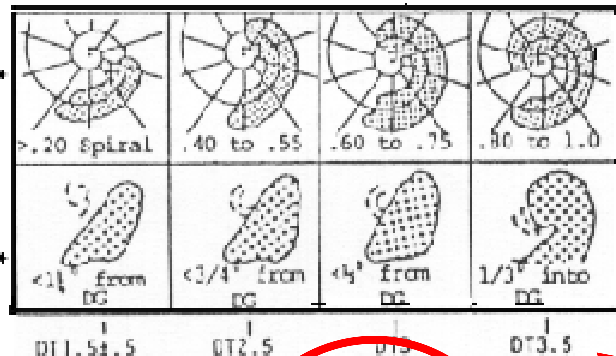
Locate the "CSC" at the focal point of all the curved cloud lines or bands. For inital development (T1), see Step 1A

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

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

2A "Curved Band" pattern
(Use spiral arc distance along 10° long spiral)

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



Add of to DT when band is white. For bands >1.0 use Vis 2A or EIR 2C

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°C
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

Can't Go Colder!!

2C "Eye" Pattern

Was 24-hr old T-no. ≥T2?
YES →
NO → Step 2A or 4

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

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

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

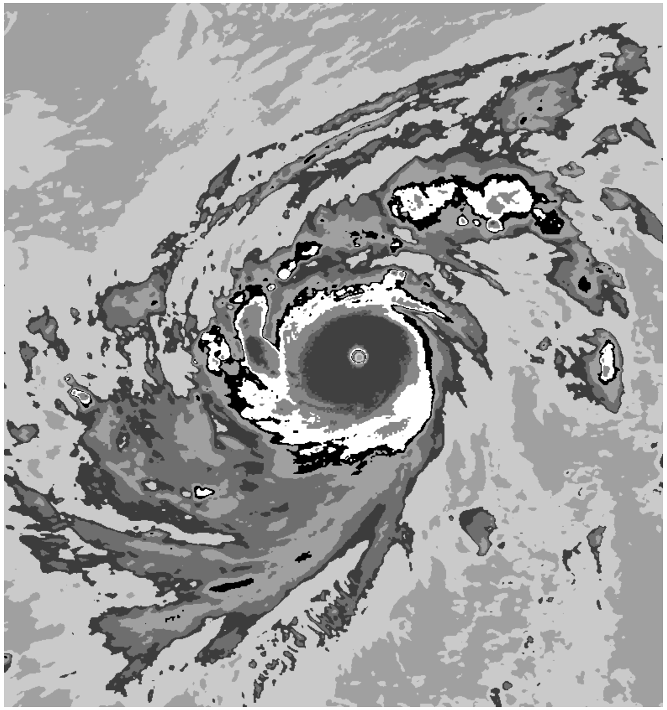
Was 12-hr old T-no. ≥T3.5?
YES →
NO → Step 2A or 4

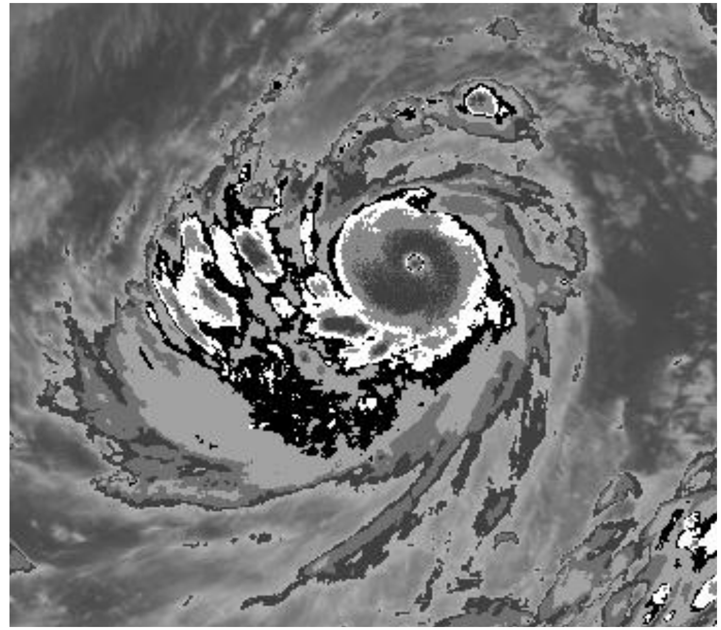
	≥.6	≥.6	≥.5	≥.5	≥.4	≥.4
	White or Colder	B	LG	MG	DG	OW
	CF5	CF5	CF4.5	CF4	CF4	CF3.5

Banding Feature (BF)?
CF + BF = DT

Results in SBC Abuse!

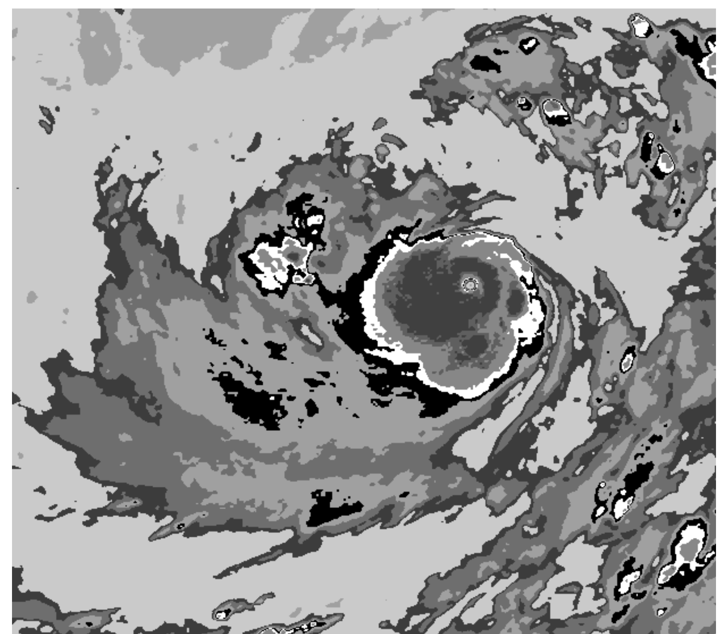
ANGELA





TIP

VANESSA



SUPER DUPER TYPHOONS
CAT 6 ??? >150 kt Sustained

CAN YOU GO GREATER
THAN T 8.0?? (170 kt Sust??)

GRAY SHADE CODE (BD CURVE)

WMG (Warm Mediun Gray). > +9 C
OW (Off White) +9 to -30 C
DG (Dark Gray) -31 to -41 C
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B (Black) -64 to -69 C
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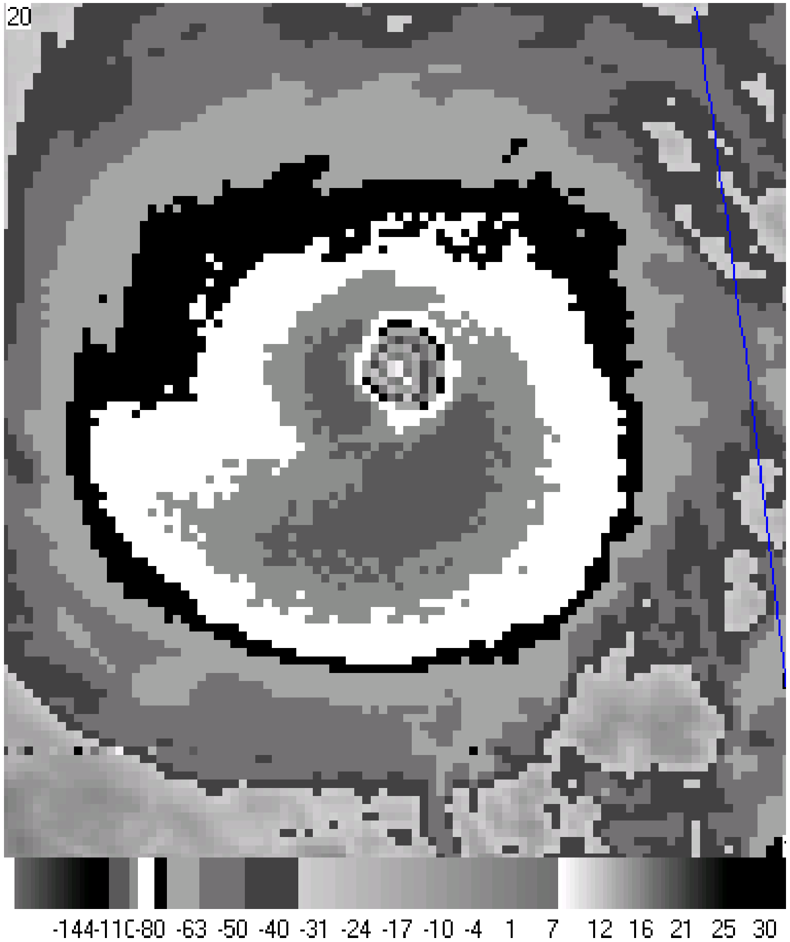
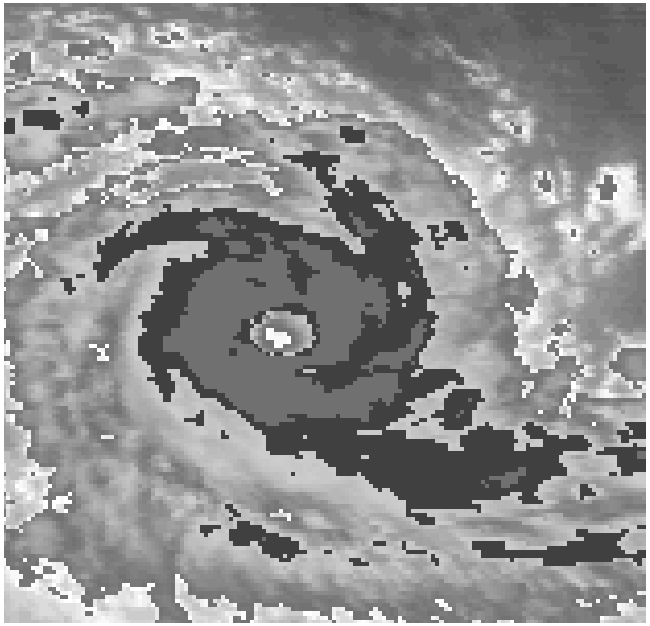


TYPHOON PODUL



HURRICANE CATARINA

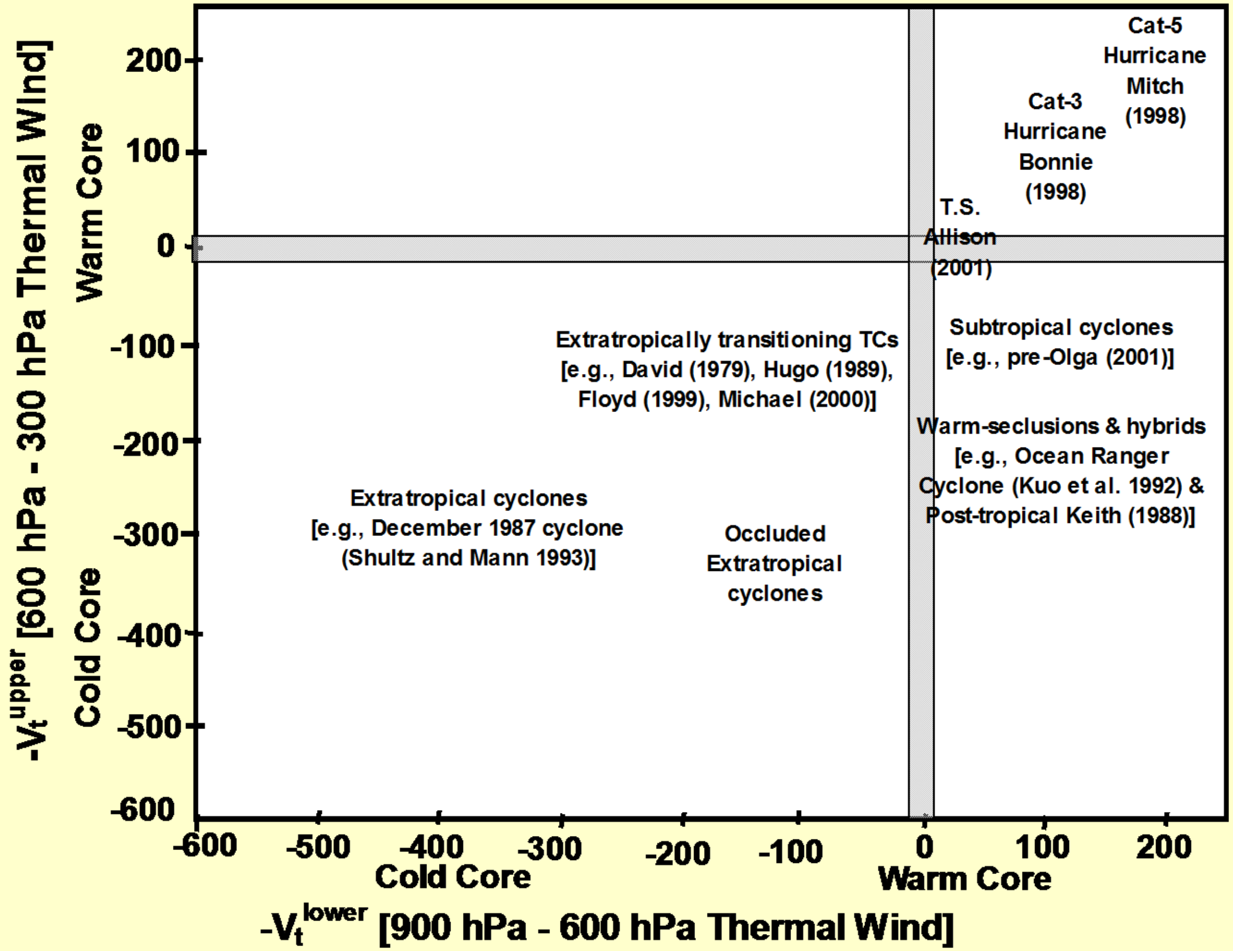
The tropopause temperature and convective cloud-top temperatures in the tropics of the western North Pacific are typically much colder than their Atlantic counterparts. Eye wall cloud-top temperatures colder than -81°C (in a complete ring) are a common occurrence in the western Pacific, but rare in the Atlantic. This is too cold to appear on the table used for the eye adjustment in Dvorak's EIR techniques. In an early paper, Shewchuk and Weir (1980) adjusted for the colder outflow temps by introducing a modified relationship between the Dvorak "T" number and wind speed.

Kossin (personal communication) found that colder cloud tops do not correlate well with greater intensity if the colder cloud tops are due to variations in tropopause height.

Emanuel (personal communication) notes that intensity is weakly correlated with ambient (but not local) tropopause temperature, while the rate of intensification might correlate with the difference between cloud-top temperature and (unperturbed) tropopause temperature.

The effects on TC intensity of these factors are not fully understood.

EXTRATROPICAL TRANSITION



Hart, R.E., 2002: A cyclone phase spacederived from thermal wind and thermal asymmetry.

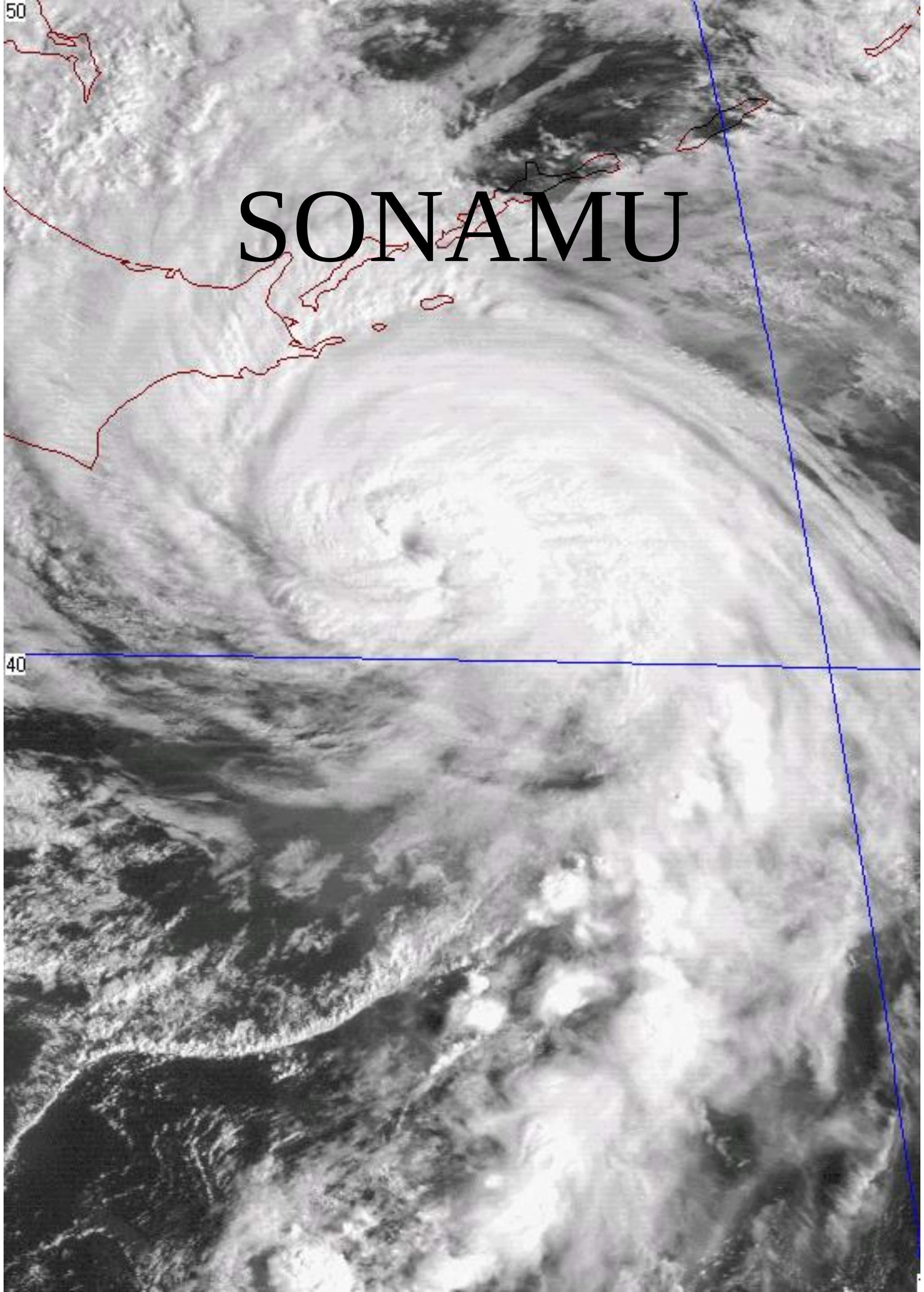
Repeatedly, when TCs begin to lose their deep convection as they undergo extratropical transition, the intensity estimates using Dvorak's techniques often fall to unrealistically low values.

In the case of Typhoon Seth moving northward towards Korea (JTWC 1994), the satellite intensity estimates were as much as three "T" numbers (35 kt) below the ship- and land-verified intensity.

At the time, JTWC satellite analysts experimented with using the **subtropical techniques of Hebert and Poteat** to derive the intensity for Seth. This still resulted in "ST" numbers equating to intensities that were far too low. The attempt to use Hebert and Poteat's classification system on TCs that are becoming extratropical is probably a misapplication.

The JTWC analysists also tried to apply to the recurving Typhoon Seth a **technique for estimating the intensity of mid-latitude cyclones from satellite imagery (Smigielski and Mogil 1992).** Again it was difficult to derive intensities high enough.

The last attempt to overcome this problem was the development of the **XT technique (Miller and Lander 1997)** for use specifically to derive from satellite imagery the intensity of TCs that are undergoing extratropical transition.



SONAMU
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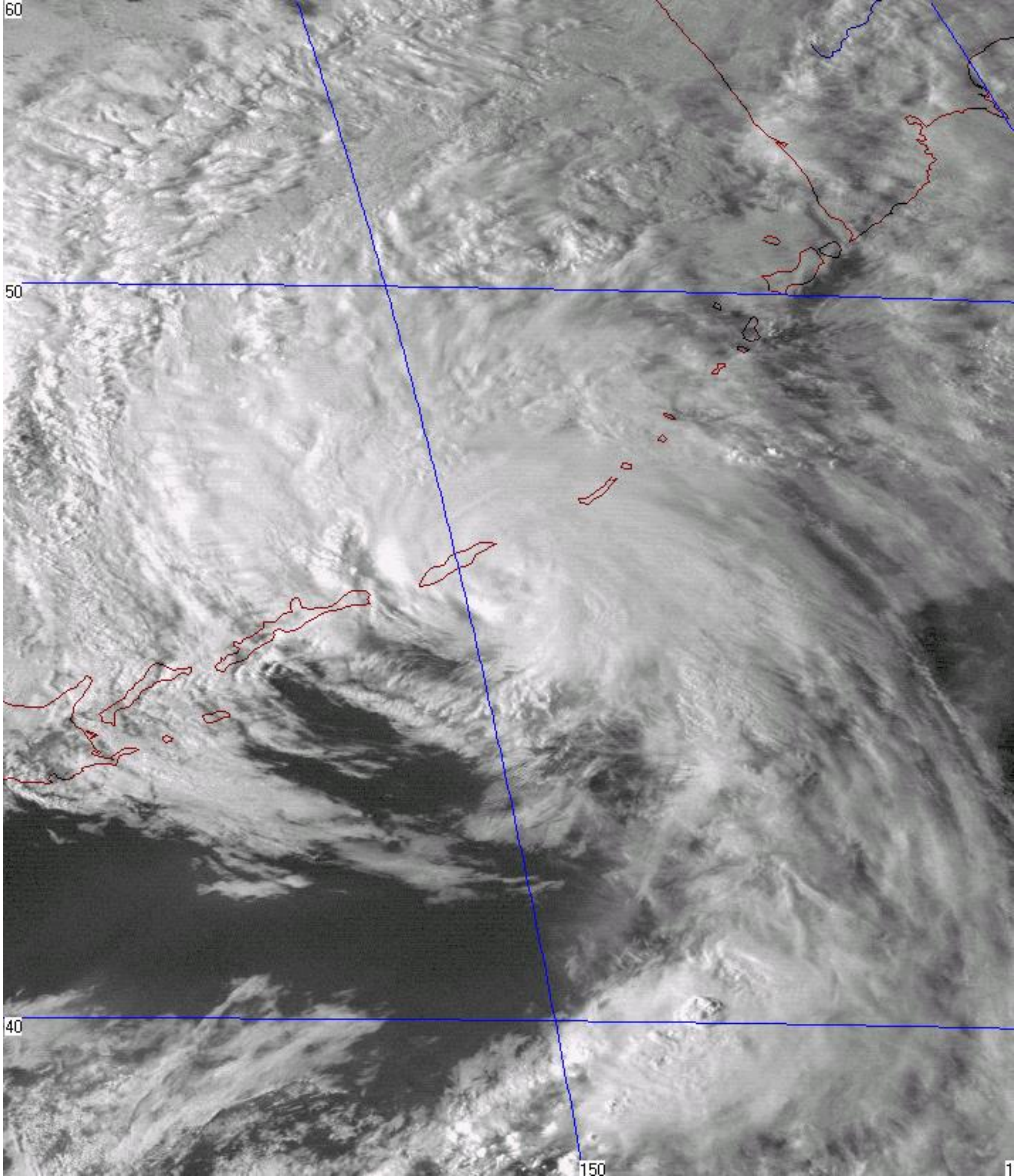
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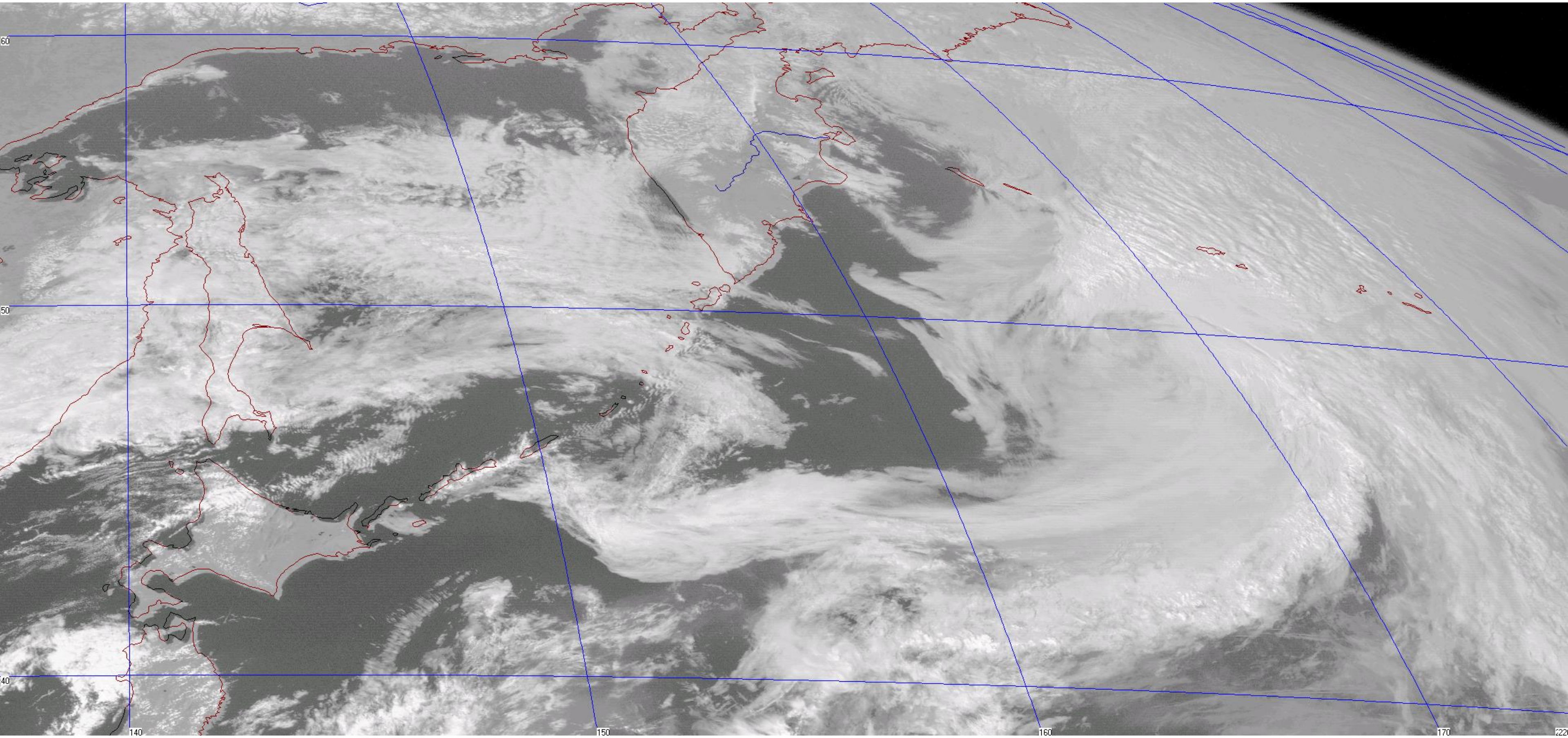
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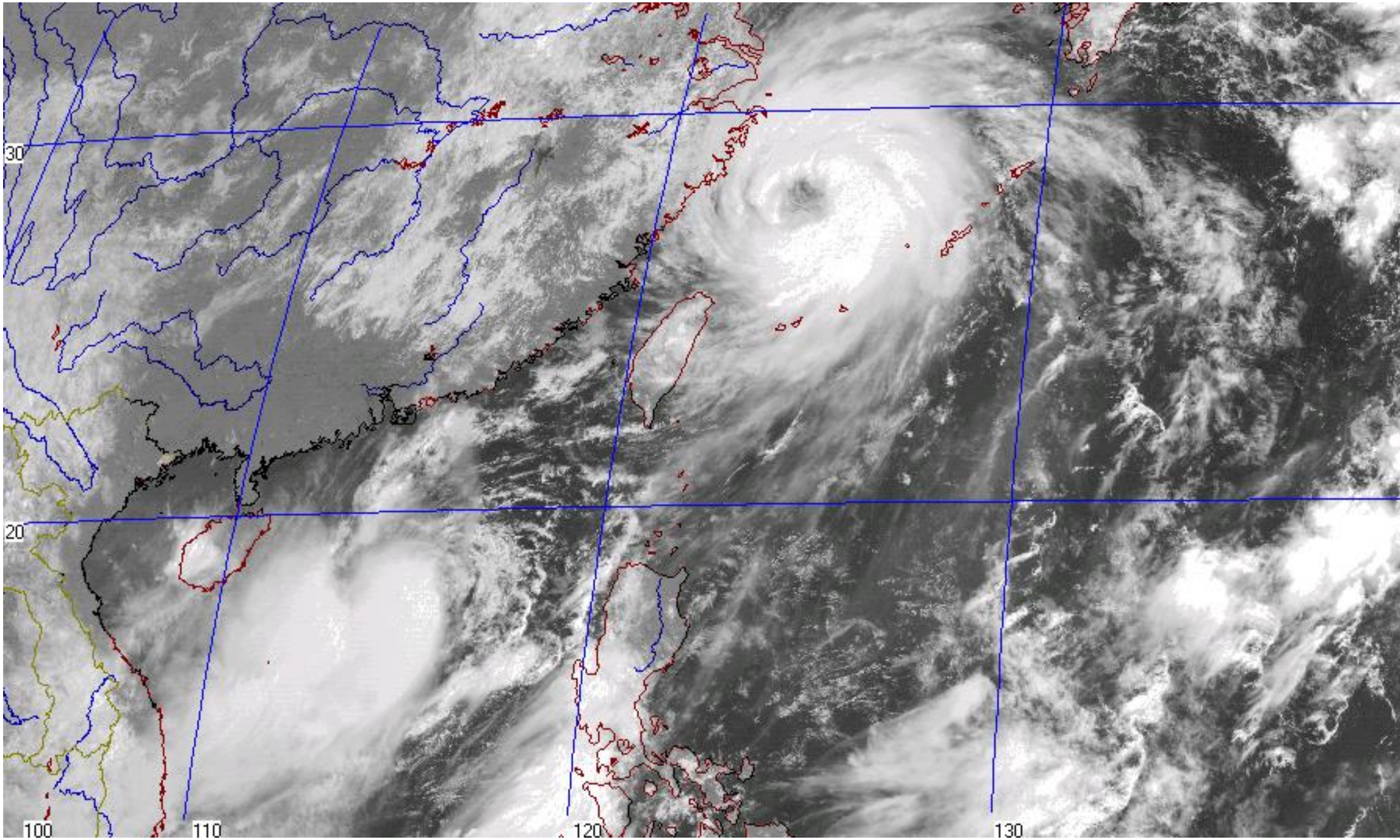
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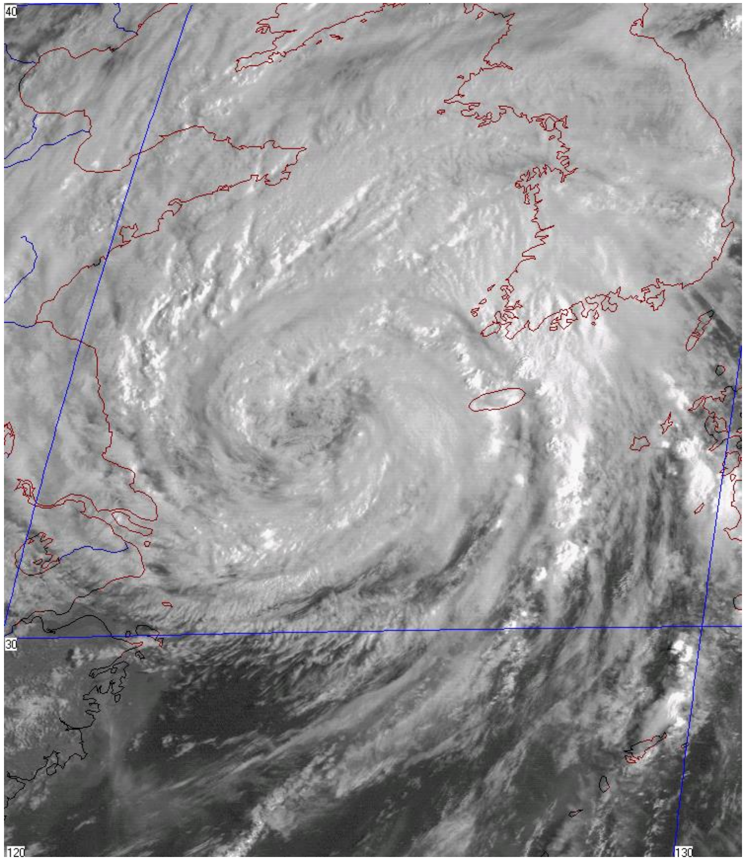
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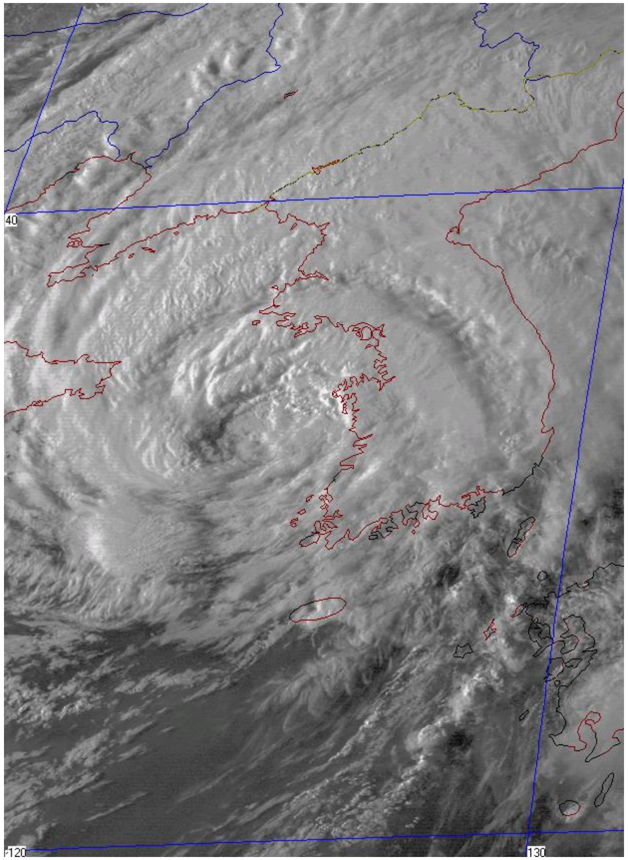
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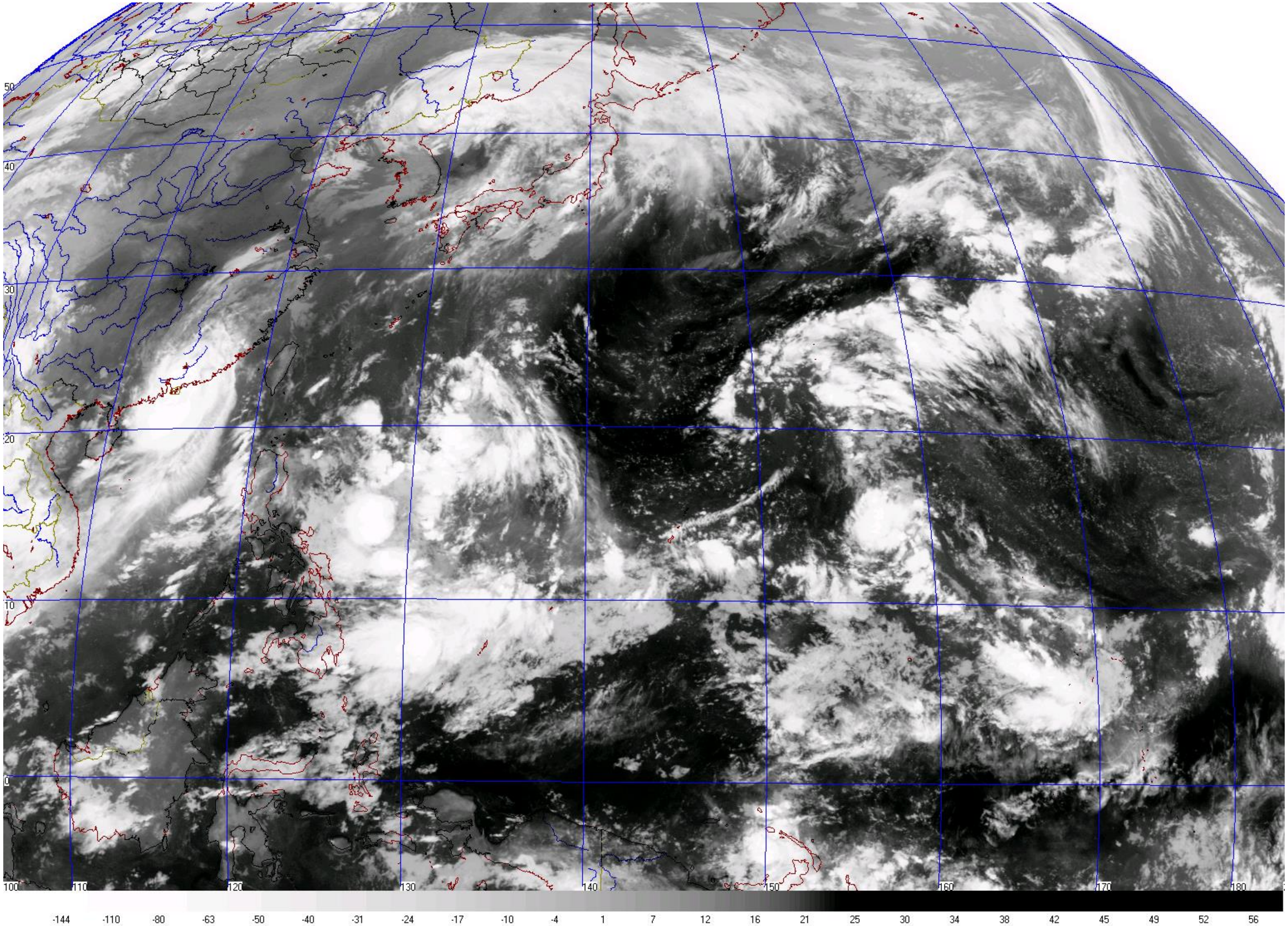
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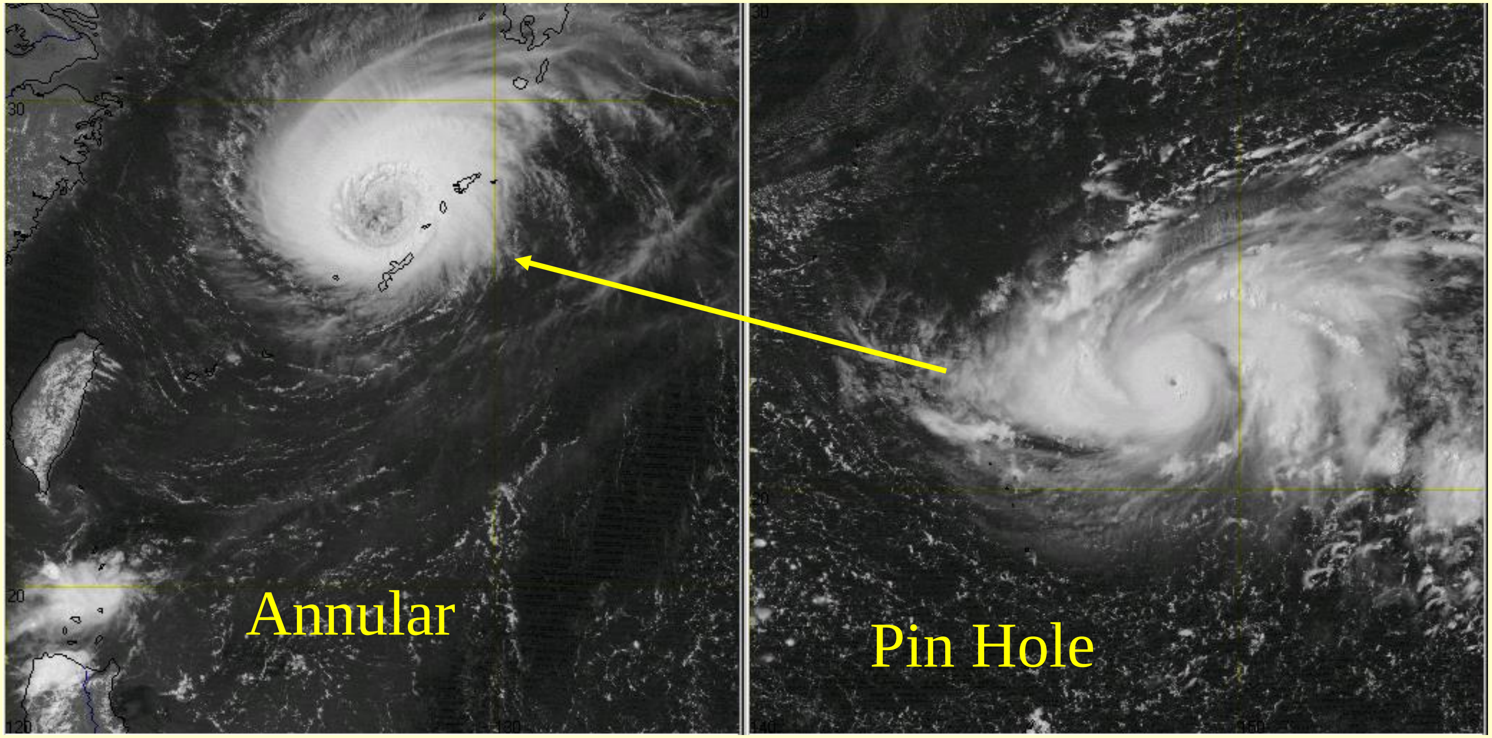
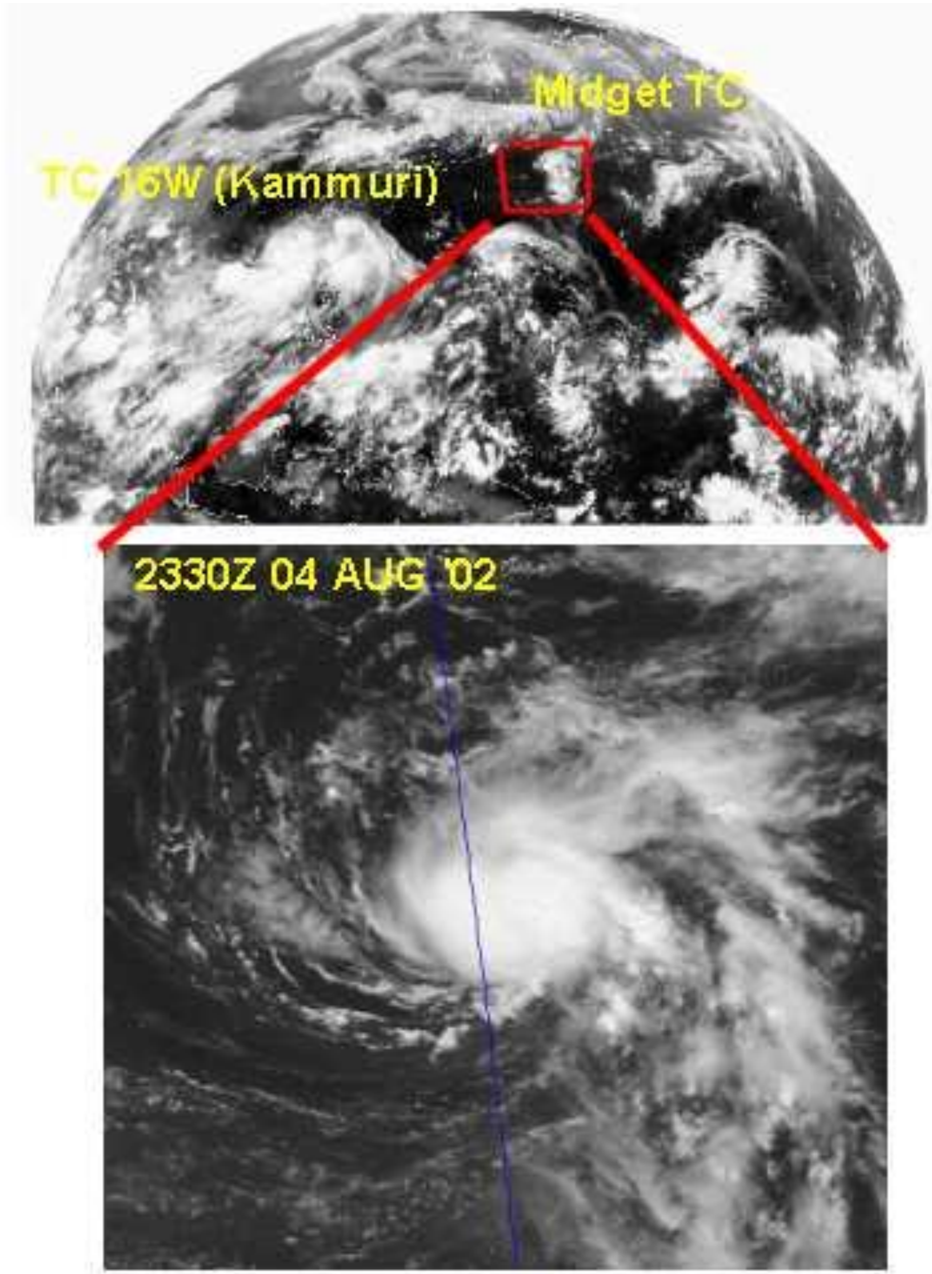
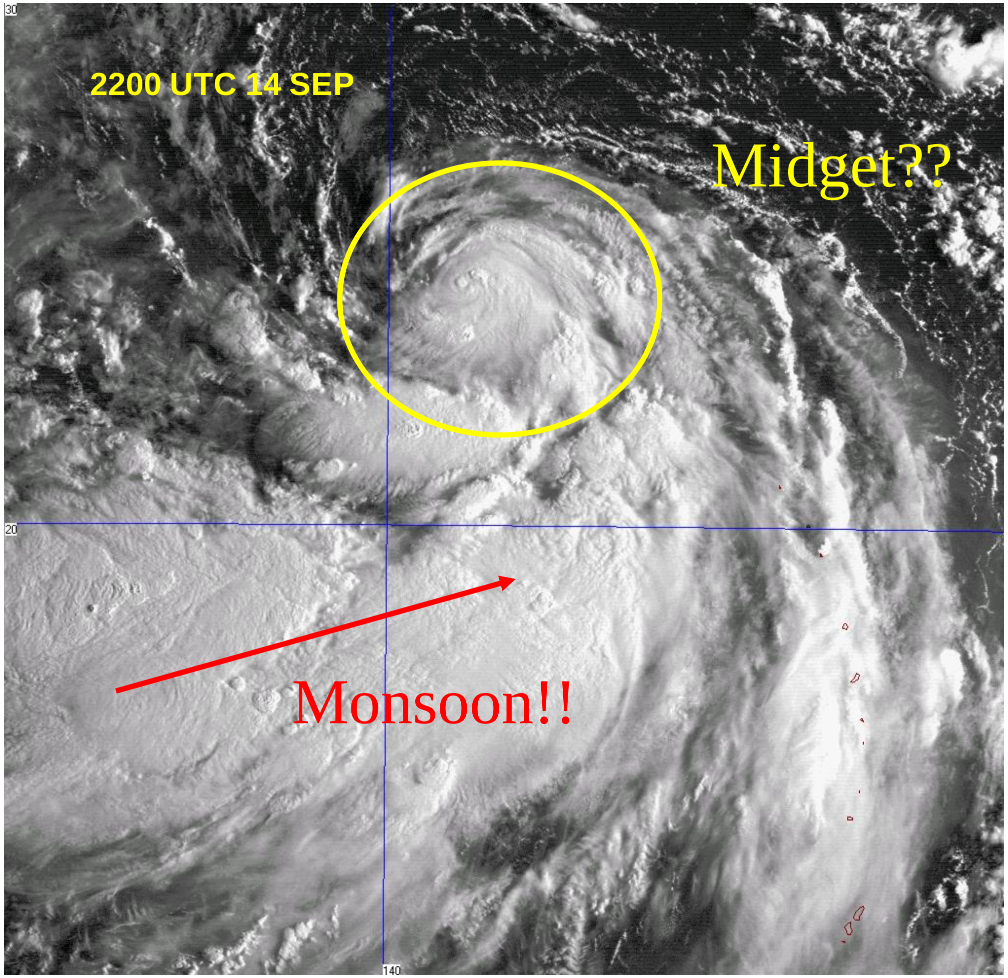
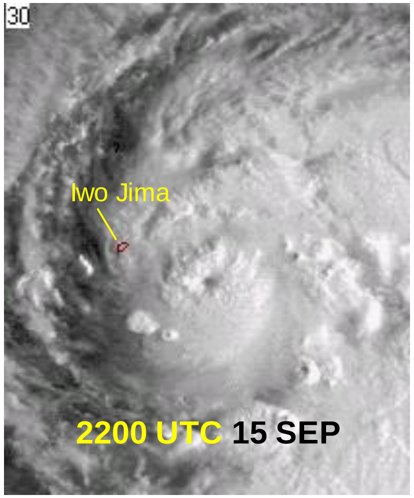
MIDGET TROPICAL CYCLONES

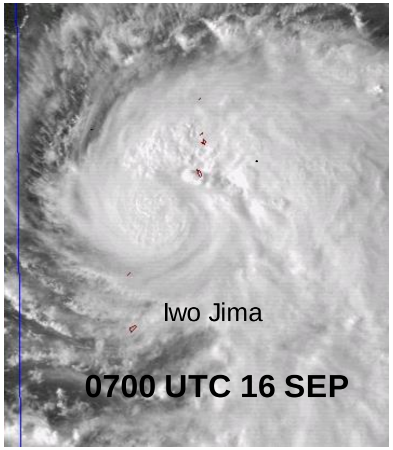


JELAWAT


Midget TC
TC 16W (Kammuri)
2330Z 04 AUG '02


30
2200 UTC 14 SEP
Midget??
20
Monsoon!!
140


30
Iwo Jima
2200 UTC 15 SEP

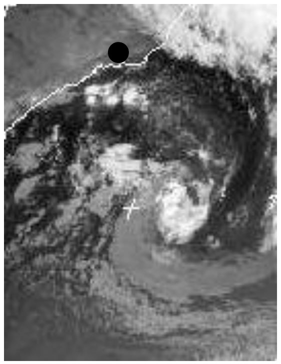

Iwo Jima
0700 UTC 16 SEP

MIDGET TROPICAL CYCLONES

- Below embedded distance constraints?
- Rapid intensity fluctuations?
- Recognition!

SUBTROPICAL CYCLONES

ST to T Transition



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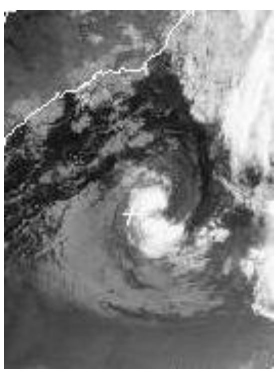

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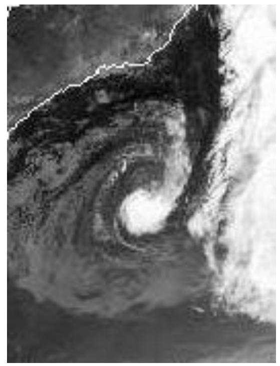


3

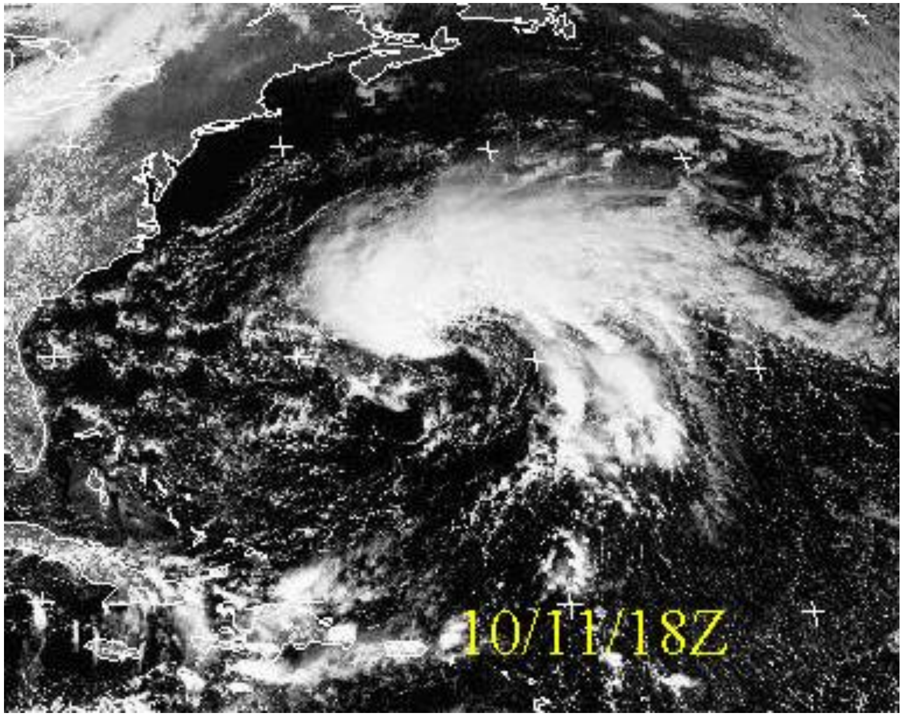
4

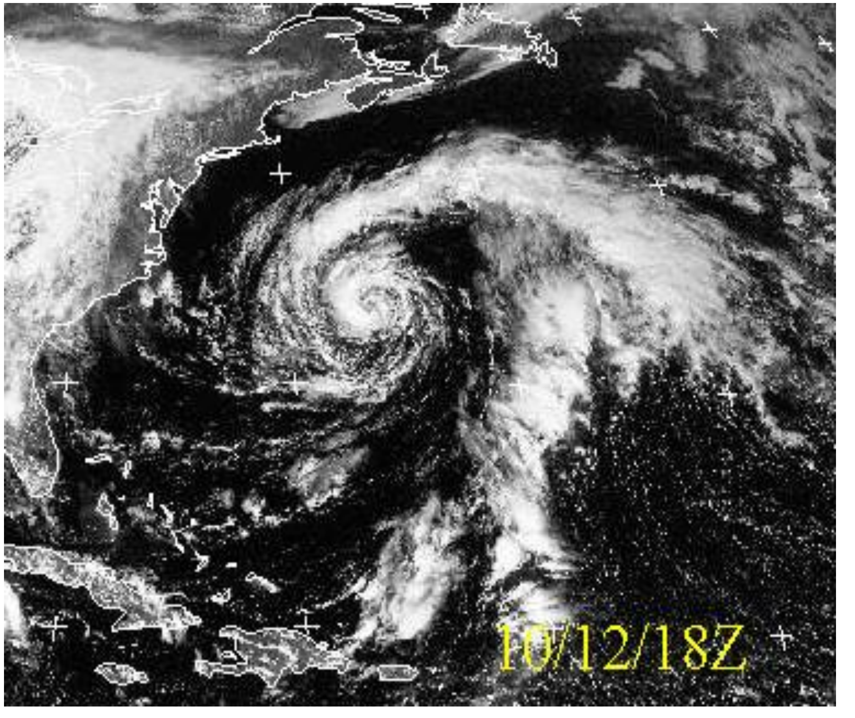
FUNDAMENTAL QUESTIONS

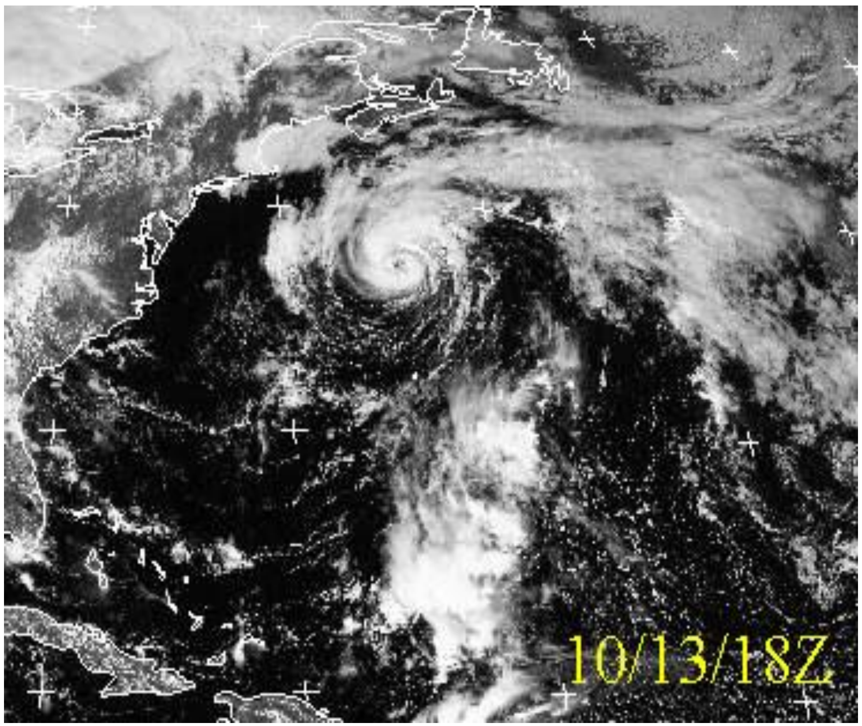
1) **is the origin of a tropical cyclone from its incipient disturbance an arbitrary classification?**

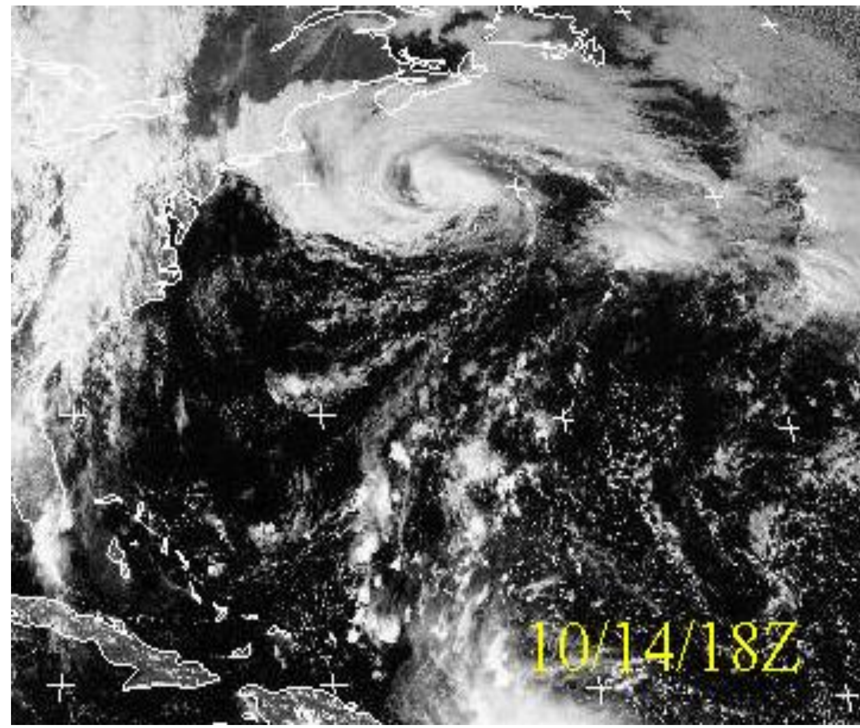
2) **When do other types of pre-existing cyclones that may already have intense and extensive cyclonic wind fields (e.g., subtropical cyclones) become tropical cyclones?**

Subtropical to Tropical

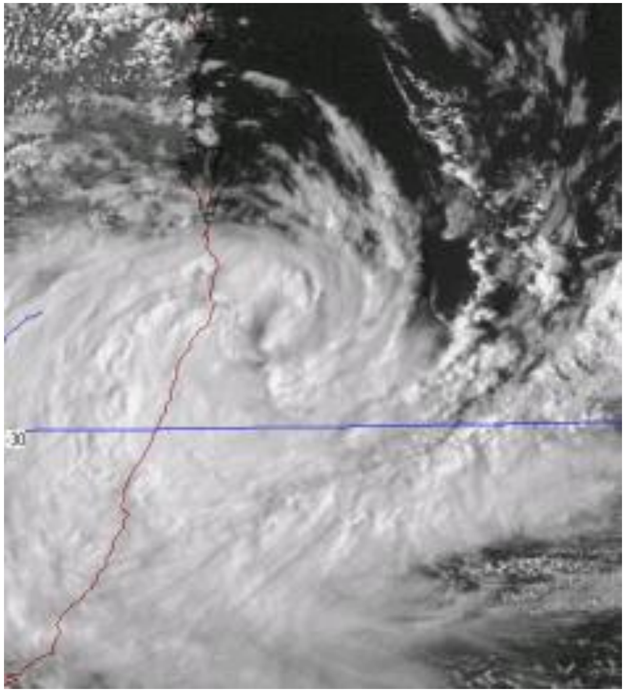


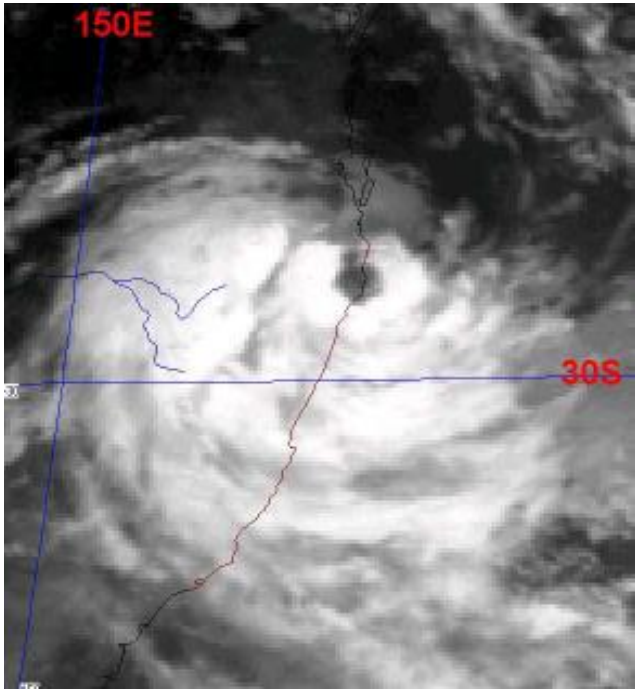



10/13/18Z


10/14/18Z

One For Greg H.





BRISBANE AUSTRALIA: The Duck

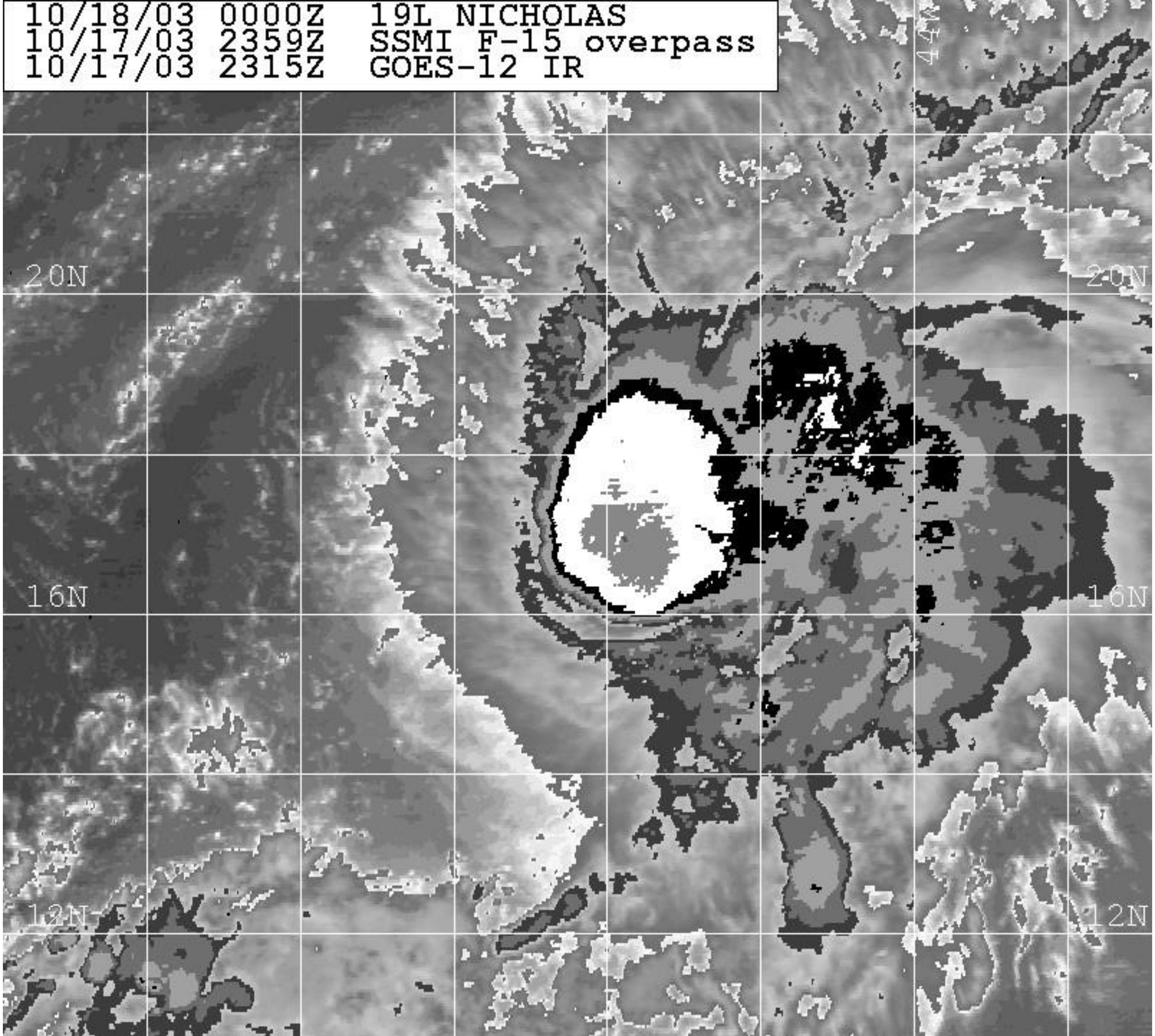
Transition of other types of cyclones into TCs

Hebert and Poteat (1974) recommended that a subtropical cyclone is considered to have a transition to a tropical cyclone if the persistent deep convection becomes located near the cyclone center so as to cover the low-level center with dense (cold on IR imagery) overcast. This conversion can be diagnosed using satellite imagery, but is often quite difficult to forecast since the evolution within numerical models is so subtle and poorly indicated using conventional analysis.

The NHC strategy to name subtropical cyclones has worked well, and all of the named subtropical cyclones have made the transition to tropical (though this need not be the case).

NEW POSSIBILTIES

- ACCOUNT FOR THE MD AND ITS EVOLUTION
- SUPPLEMENTAL INFO FROM MI?
- DO EXTREME CLOUD-TOP TEMPS EQUATE TO EXTREME INTENSITY?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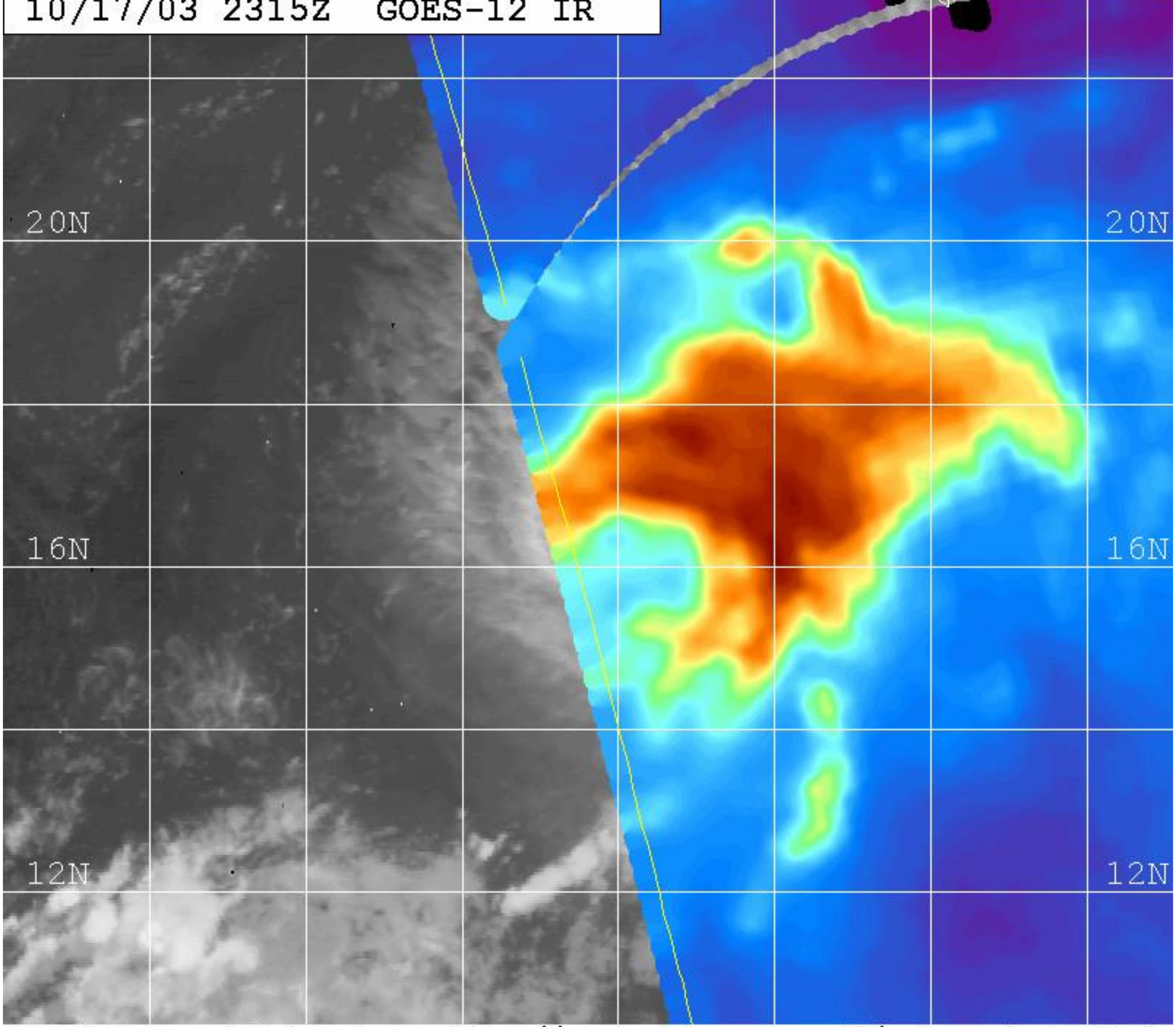
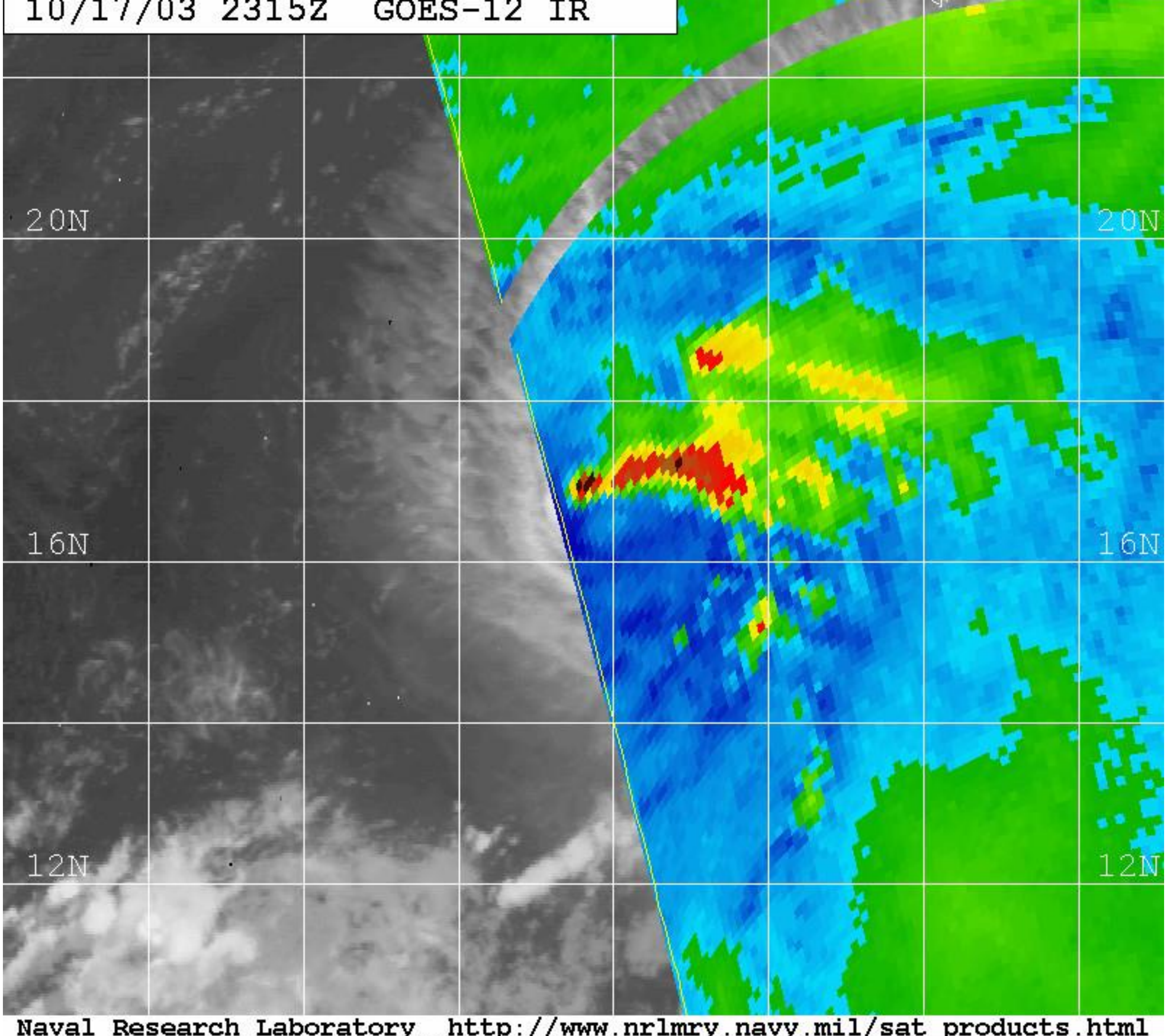
10/17/03 2359Z SSMI F-15 overpass
10/17/03 2315Z GOES-12 IR
44W
20N
20N
16N
16N
12N
12N



Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html


10/17/03 2315Z GOES-12 IR
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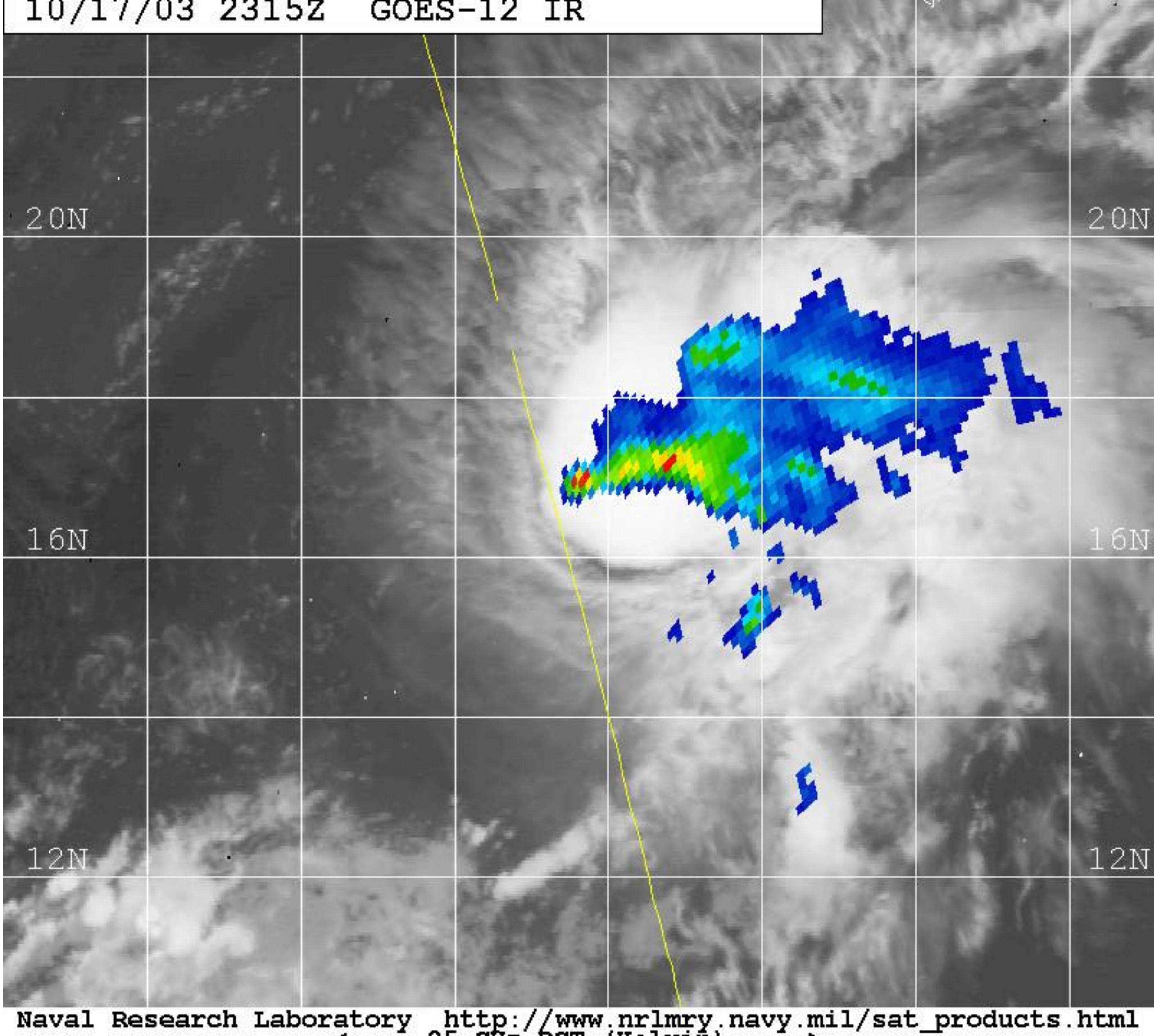
10/17/03 2315Z GOES-12 IR
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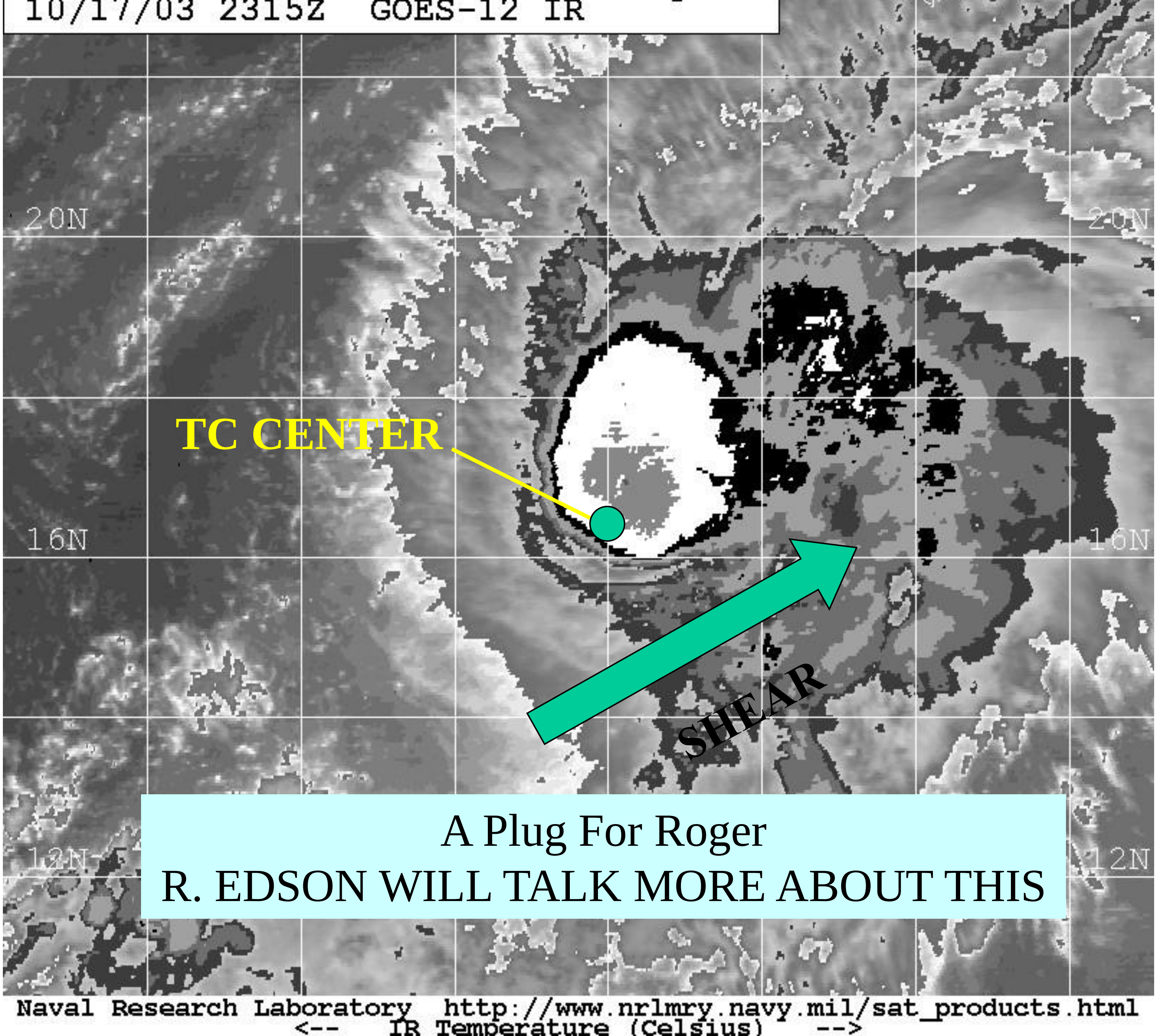
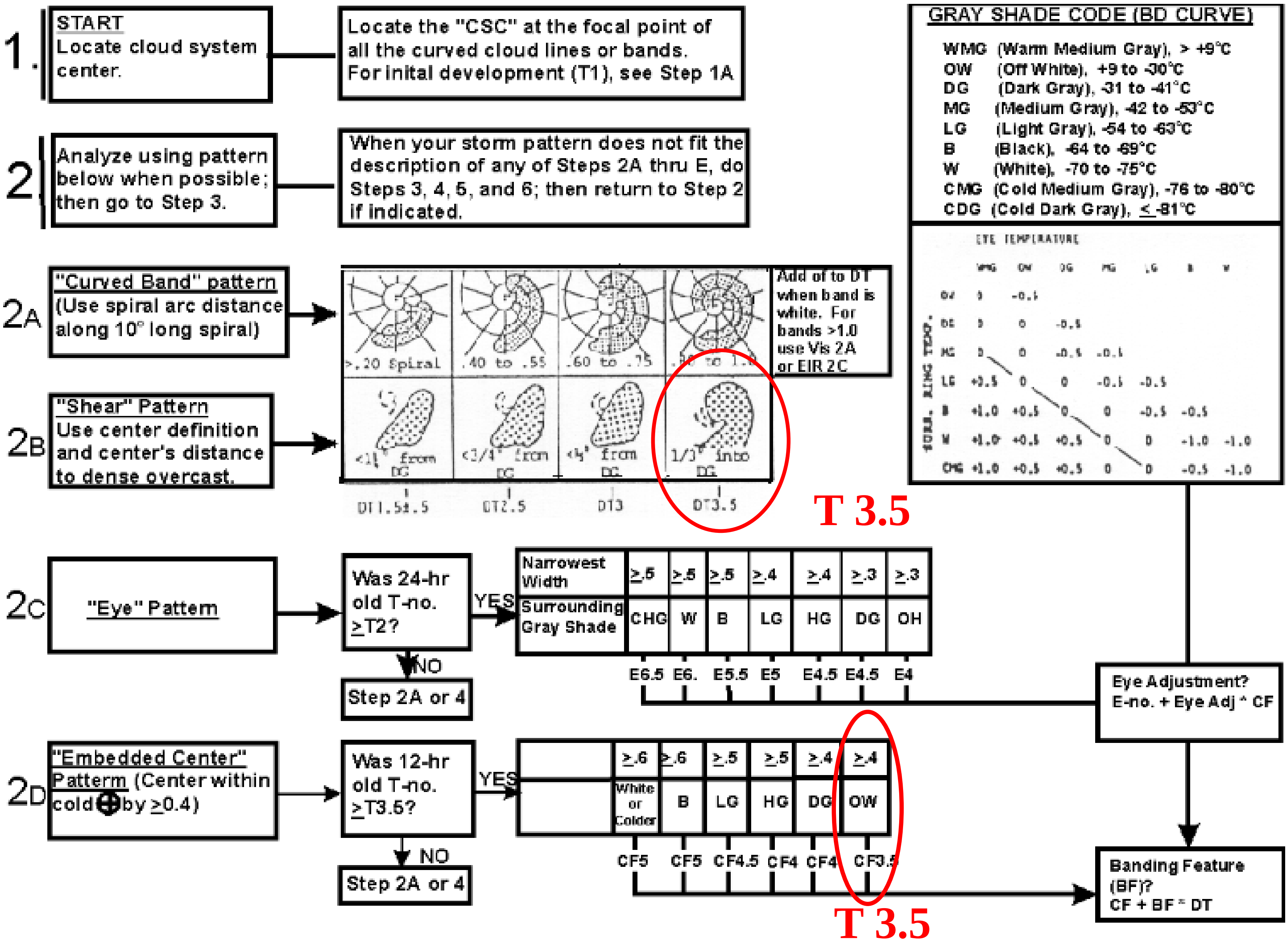


A Plug For Roger

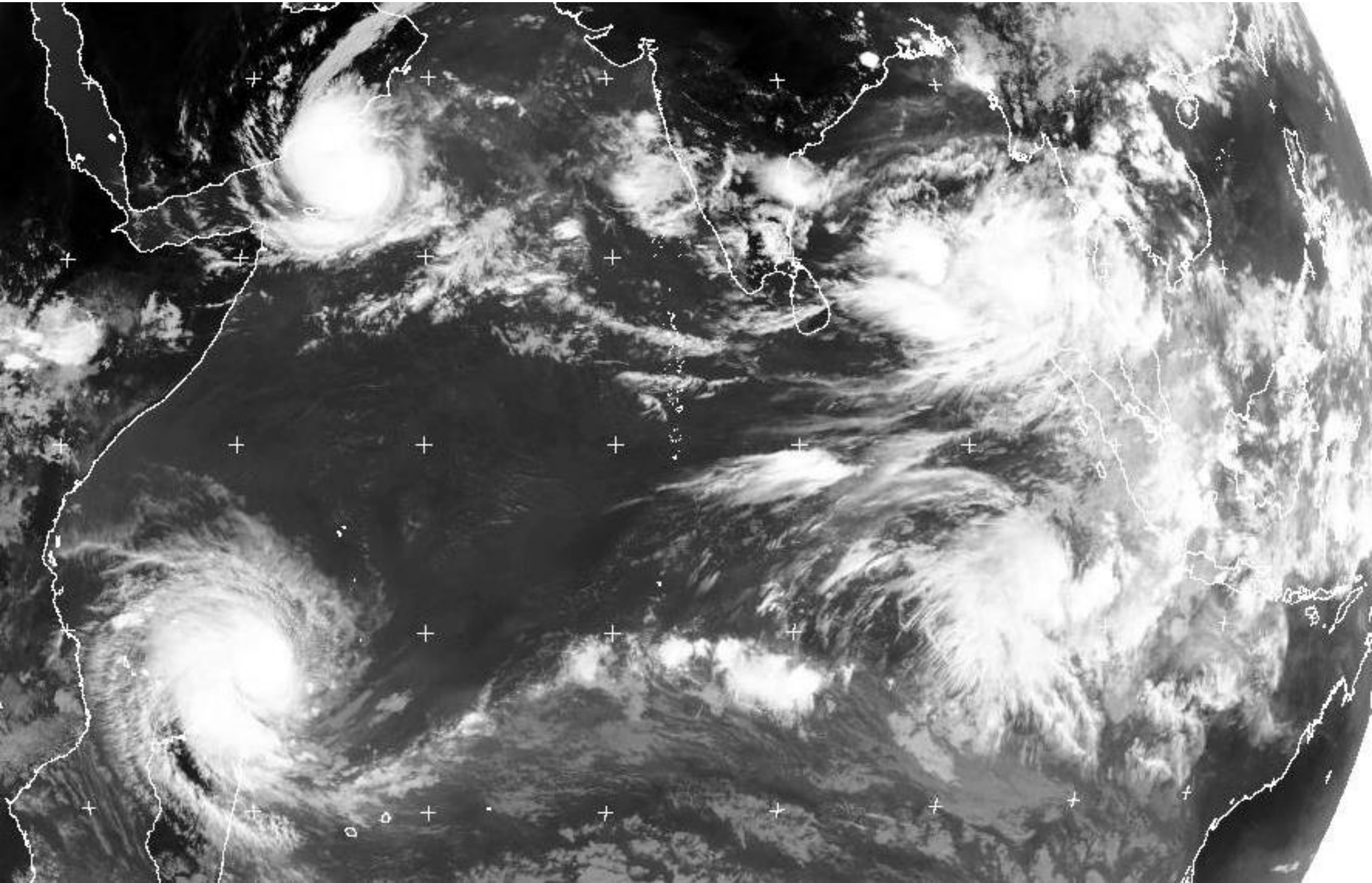
R. EDSON WILL TALK MORE ABOUT THIS


1.
START
Locate cloud system center.
Locate the "CSC" at the focal point of all the curved cloud lines or bands.
For inital development (T1), see Step 1A
2
Analyze using pattern below when possible; then go to Step 3.
When your storm pattern does not fit the description of any of Steps 2A thru E, do Steps 3, 4, 5, and 6; then return to Step 2 if indicated.
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°C
CDG (Cold Dark Gray), ≤ -81°C
EYE TEMPERATURE
2A
"Curved Band" pattern
(Use spiral arc distance along 10° long spiral)
>.20 Spiral
.40 to .55
.60 to .75
Add of to DT when band is white. For bands >1.0 use Vis 2A or EIR 2C
2B
"Shear" Pattern
Use center definition and center's distance to dense overcast.
from DG
<1/4° from DG
1/3° into DG
DT1.5±.5
DT2.5
DT3
DT3.5
T 3.5
2C
"Eye" Pattern
Was 24-hr old T-no. ≥T2?
YES
NO
Step 2A or 4
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
Eye Adjustment?
E-no. + Eye Adj = CF
2D
"Embedded Center" Pattern (Center within cold by ≥0.4)
Was 12-hr old T-no. ≥T3.5?
YES
NO
Step 2A or 4
≥.6
≥.6
≥.5
≥.5
≥.4
≥.4
White or Colder
B
LG
MG
DG
OW
CF5
CF5
CF4.5
CF4
CF4
CF3.5
Banding Feature (BF)?
CF + BF = DT
T 3.5

CONCLUSIONS

Dvorak's techniques for estimating TC intensity from satellite imagery have been used operationally around the world for nearly 30 years. They have not been superceded or substantially modified in all that time. Largely developed from data on Atlantic TCs, users of the techniques in other basins have encountered a few minor problems. Some problems such as extratropical transition are common to all basins. New remote-sensing data and techniques such as the XT technique should nicely complement Dvorak's techniques and fill-in the fringe areas.

END OF TALK



DVORAK RULES FOR EIR IMAGERY (Continued)

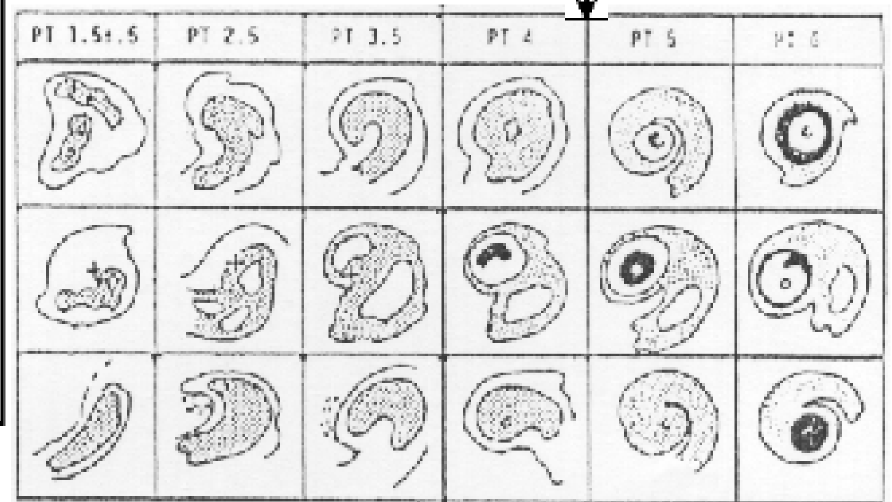
3 "Central Cold Cover" Pattern

Rules: When past T-no. ≤T3, maintain model trend for 12 hours; then hold same. When past T-no. ≥T35 hold T-no. same. Use as final T-no.; then go to Step 9.

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

5 Determine Model Expected T-no (MET).

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



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

7 T-no. Determination:

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

8 Final T-number Constraints:

1. Initial classification must be T1 or T1.5
2. During first 48 hours of development, T-no cannot be lowered at night.
3. 24 hrs after inital T1, storm's T-no. must be <T4:
4. Final T-no. limits: <T4: change of 1/2 over 6 hours, 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:

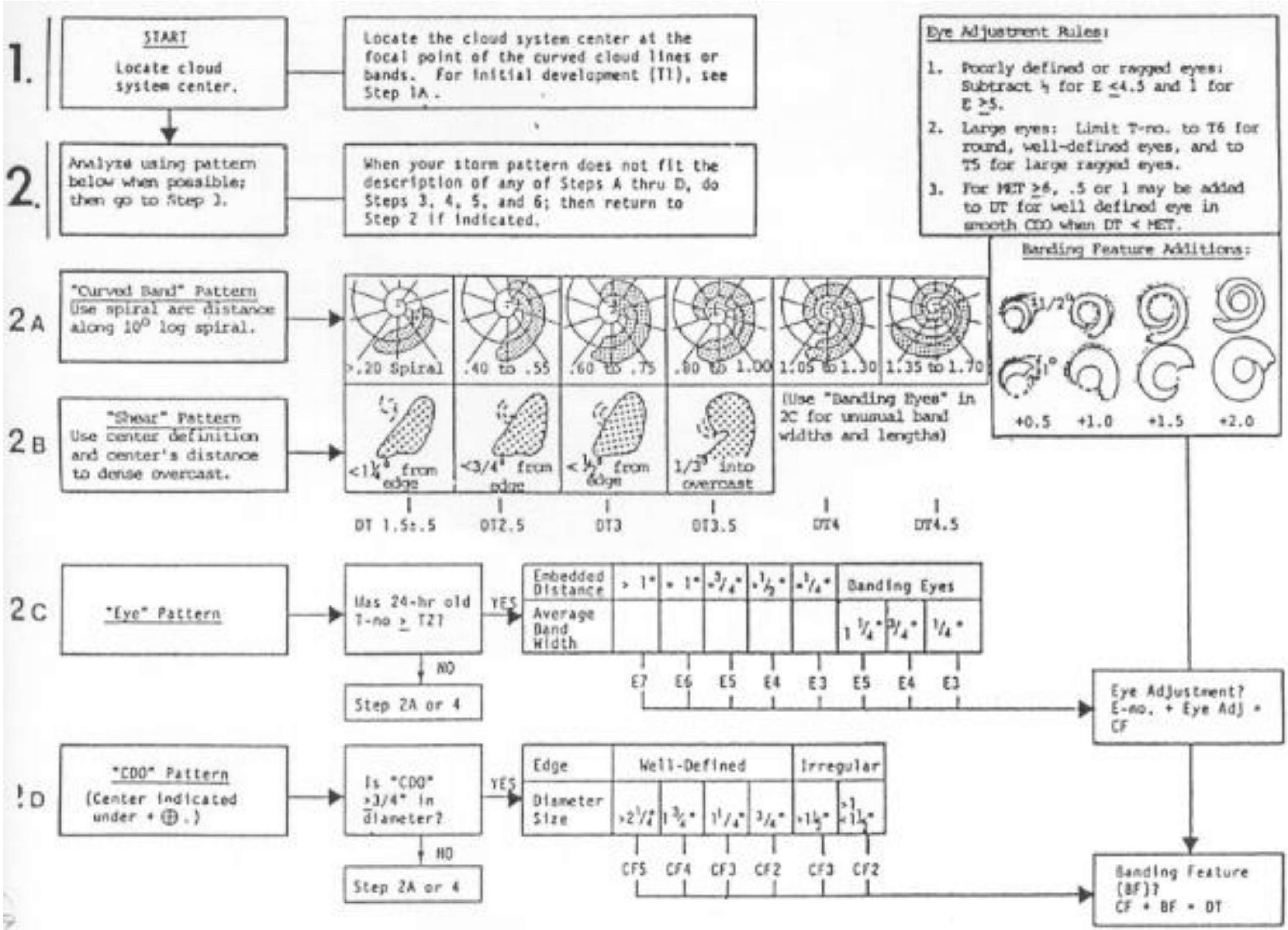
1. Use CI = final T-no. except when final T-no. shows change to weakening trend, or when redevelopment is indicated
2. For initial weakening, hold CI same for 12 hours, then hold CI 1/2 or 1 higher than T-no. as storm weakens.

10 24-Hr Forecast:

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

FCST

DVORAK RULES FOR VIS IMAGERY



DVORAK RULES FOR VIS IMAGERY (Continued)

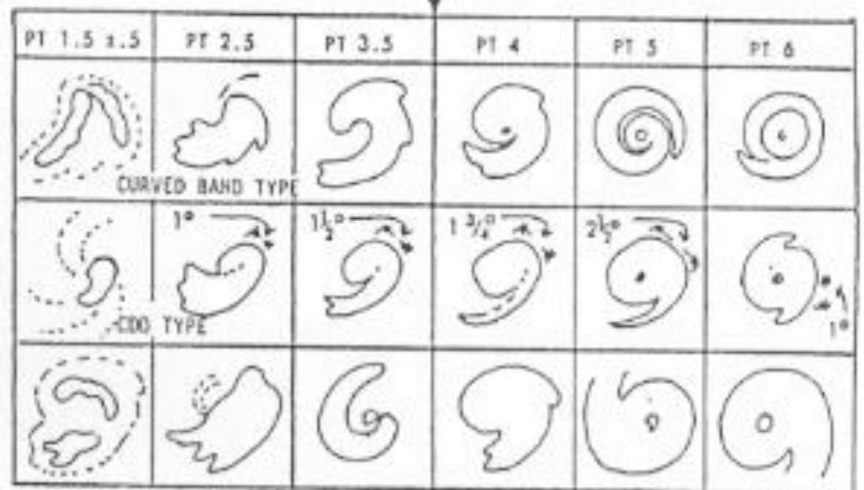
3. "Central Cold (Dense) Cover" Pattern

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

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

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

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



When cloud comma is extremely small (<$2\frac{1}{2}$° 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.

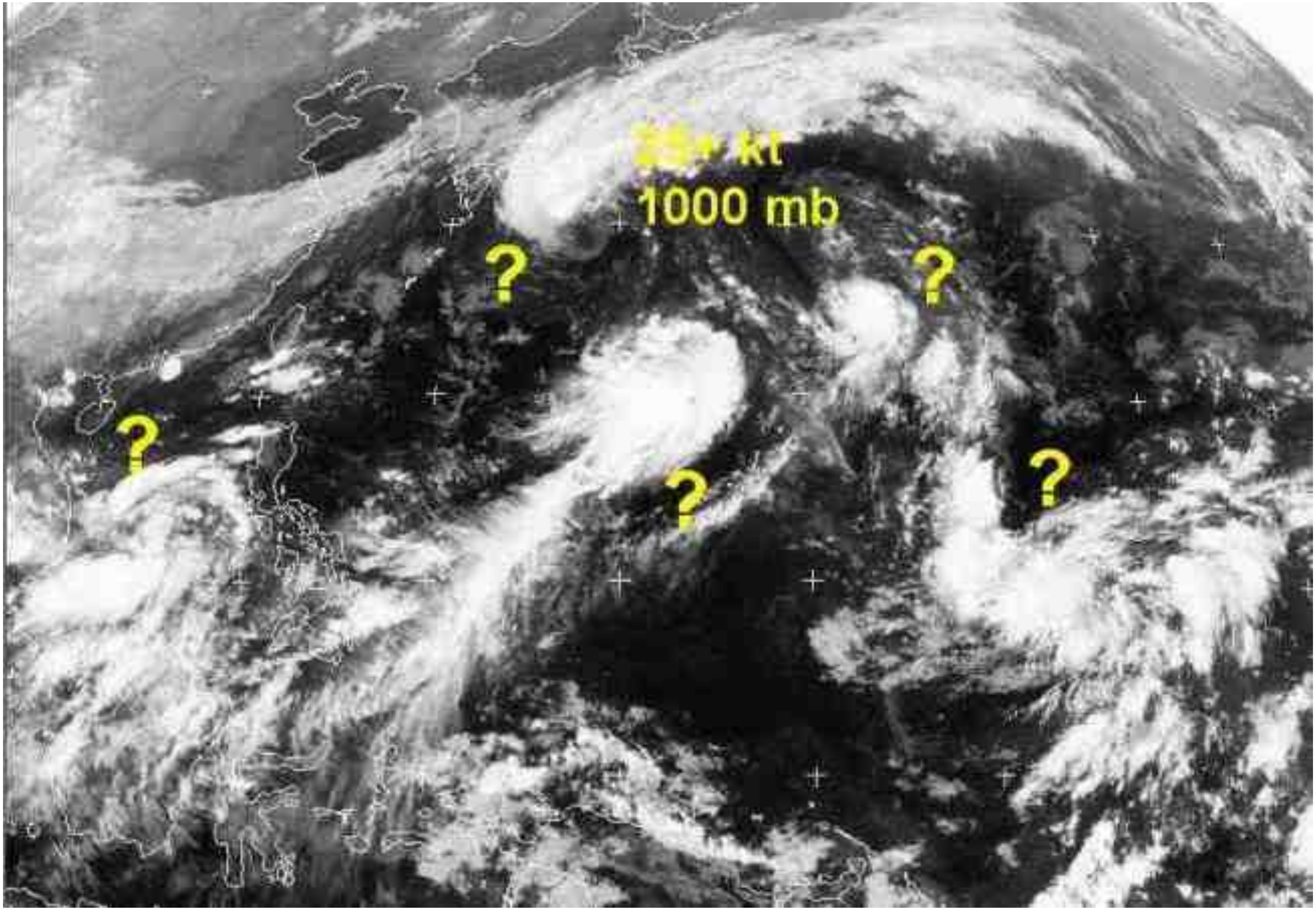
9. Current Intensity (CI) Number Rules:

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.

FCST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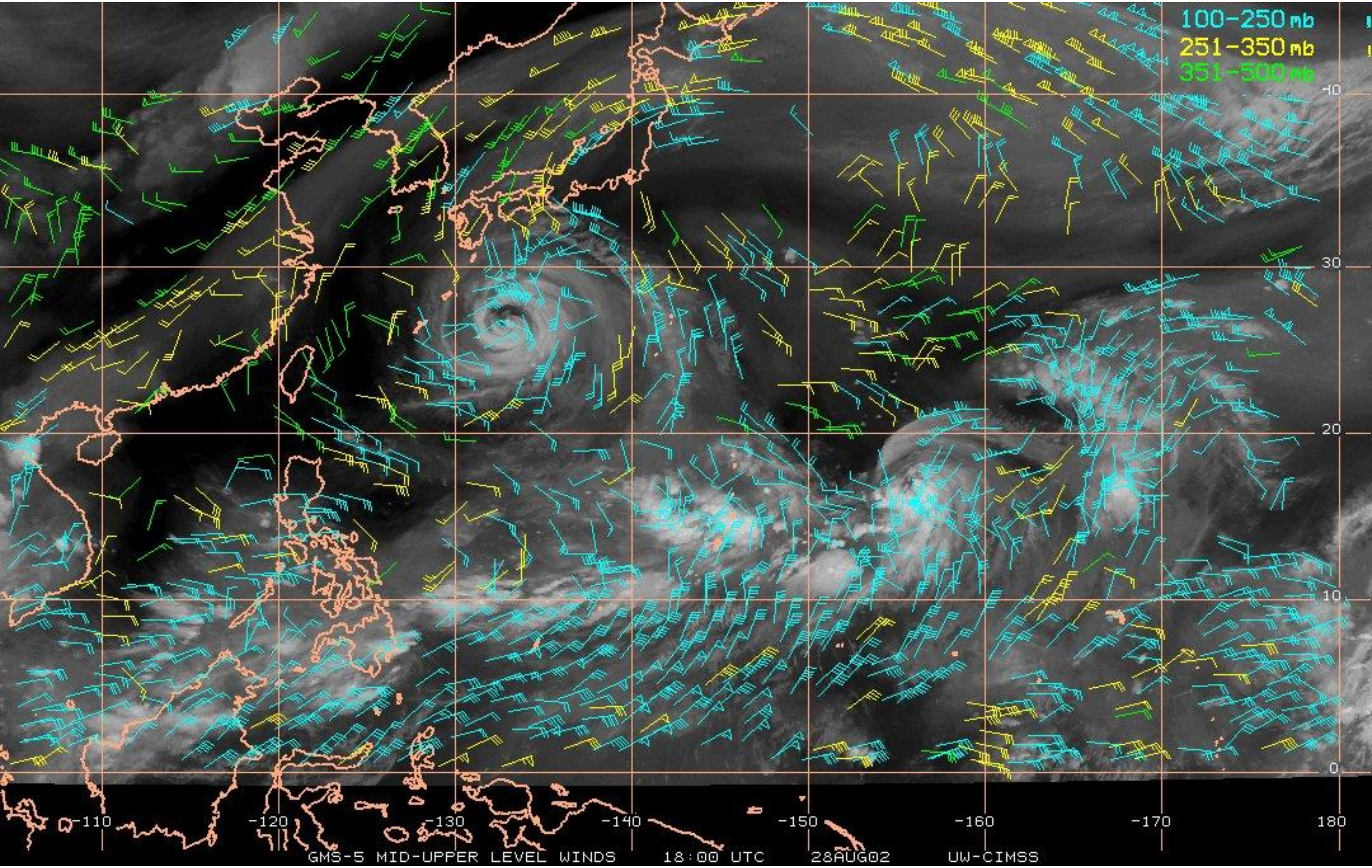
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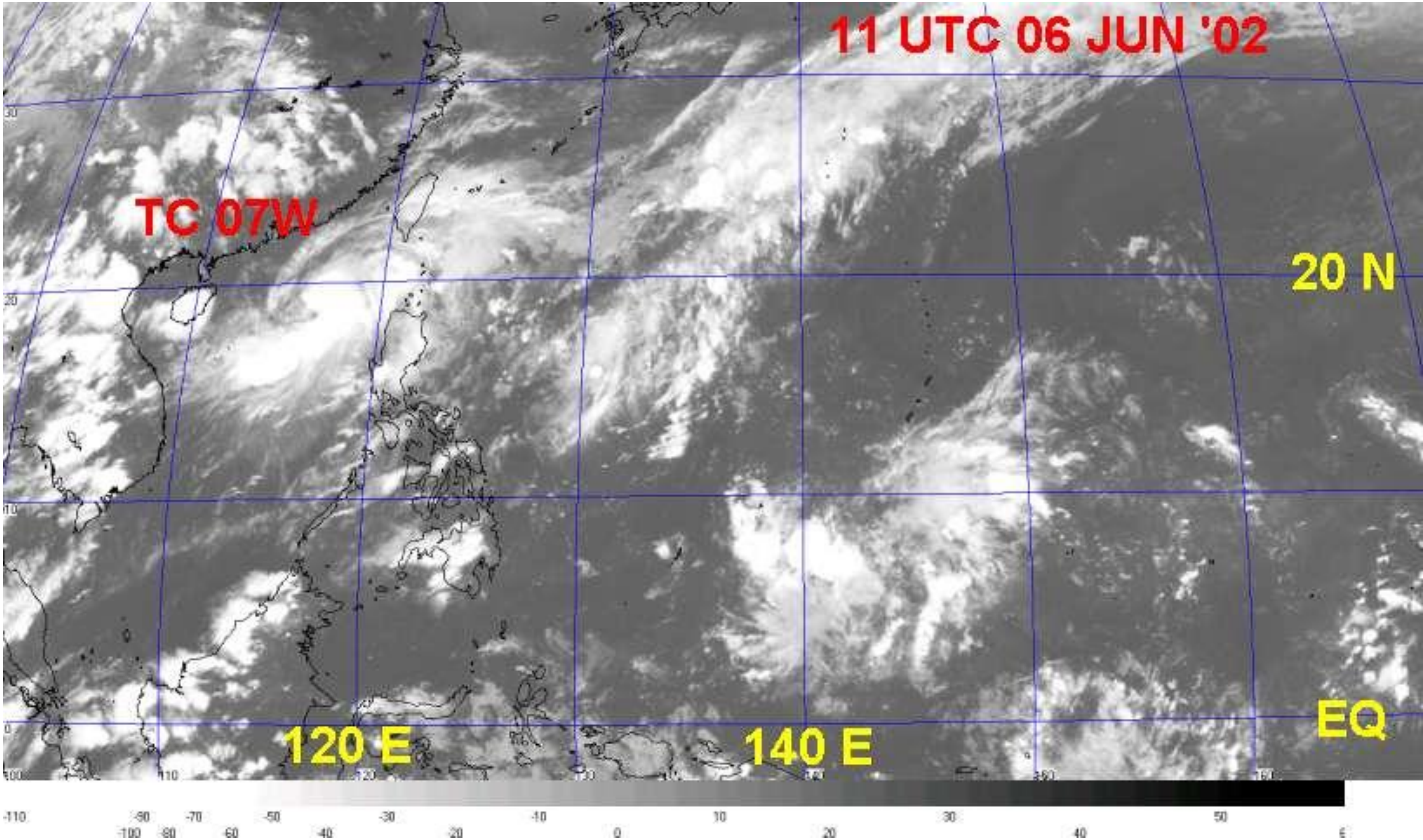
GMS-5 MID-UPPER LEVEL WINDS 18:00 UTC 28AUG02 UW-CIMSS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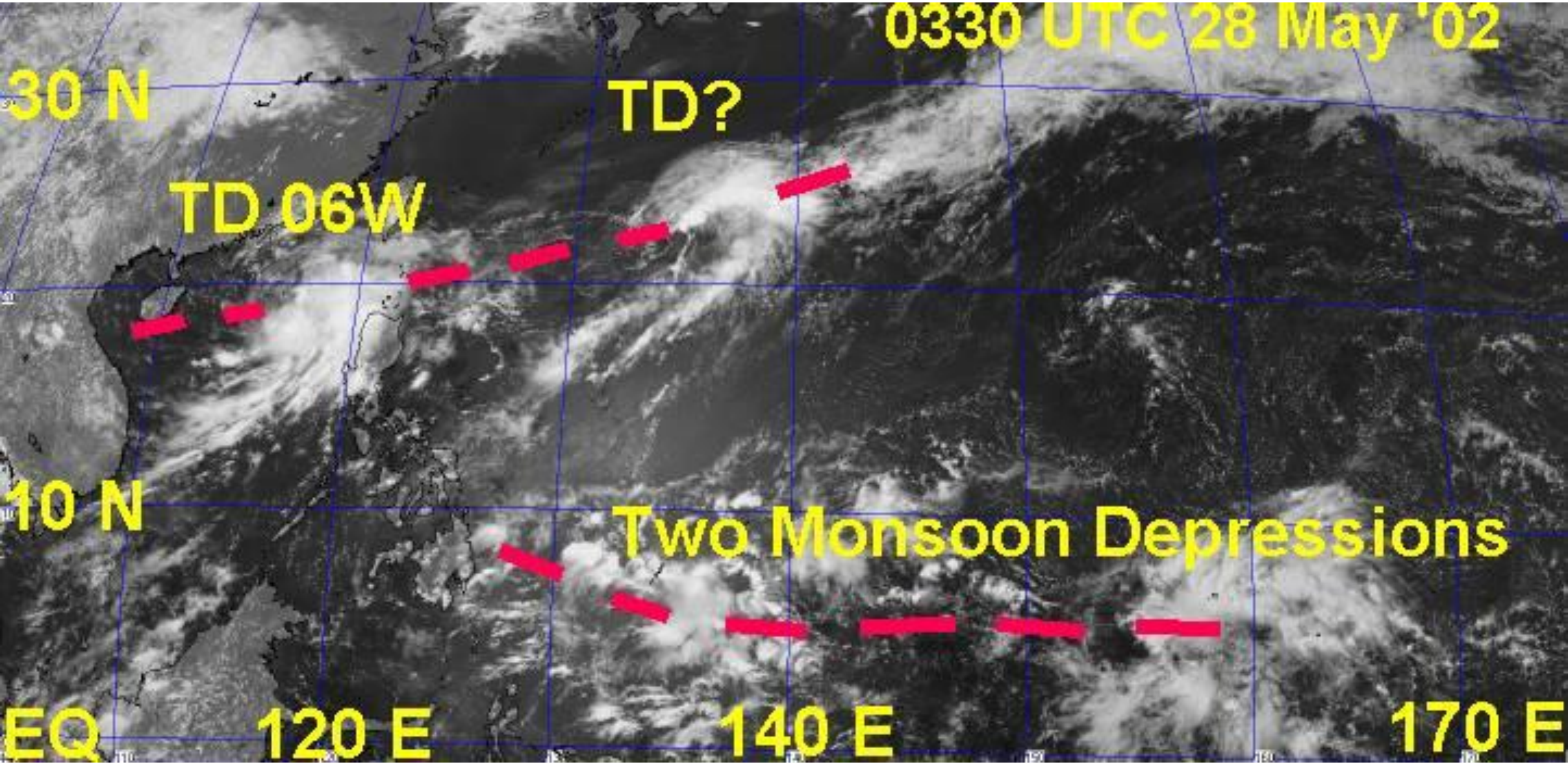
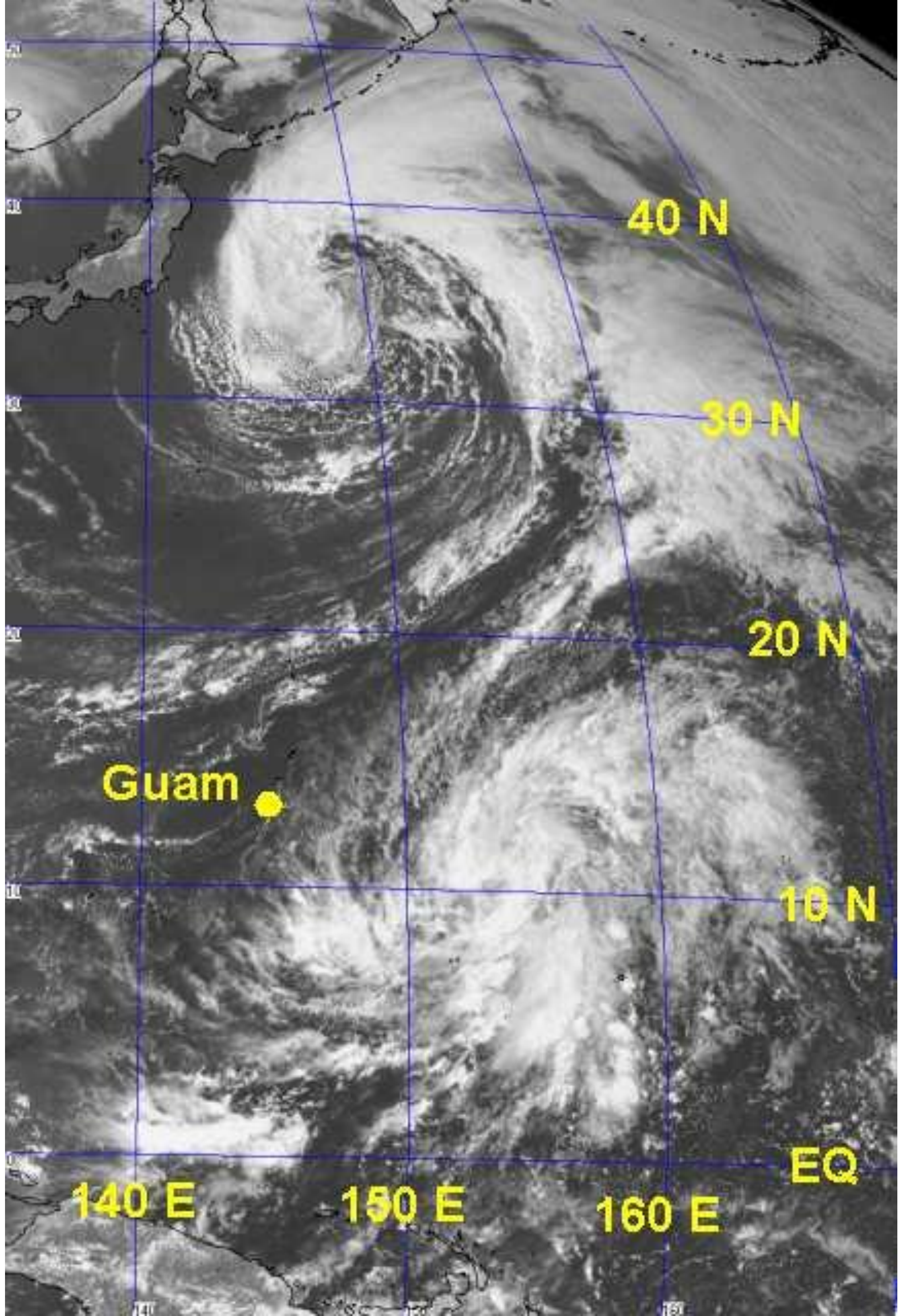
TC 07W
20 N
EQ
120 E
140 E


0330 UTC 28 May '02
30 N
TD?
TD 06W
10 N
Two Monsoon Depressions
EQ
120 E
140 E
170 E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30 N
20 N
Guam
10 N
EQ
140 E
150 E
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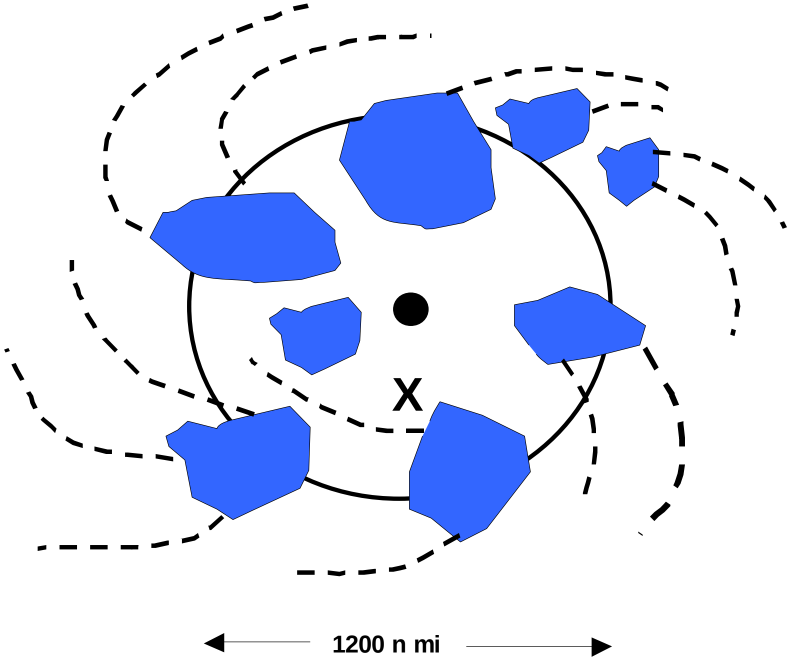
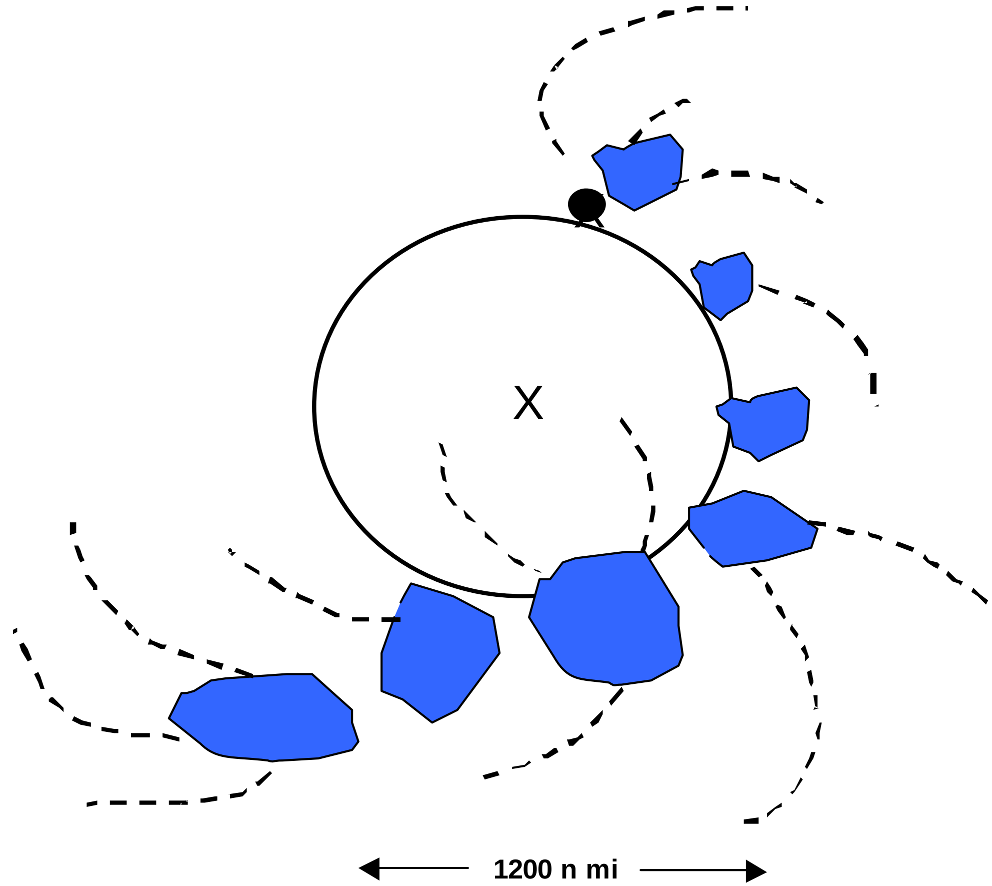
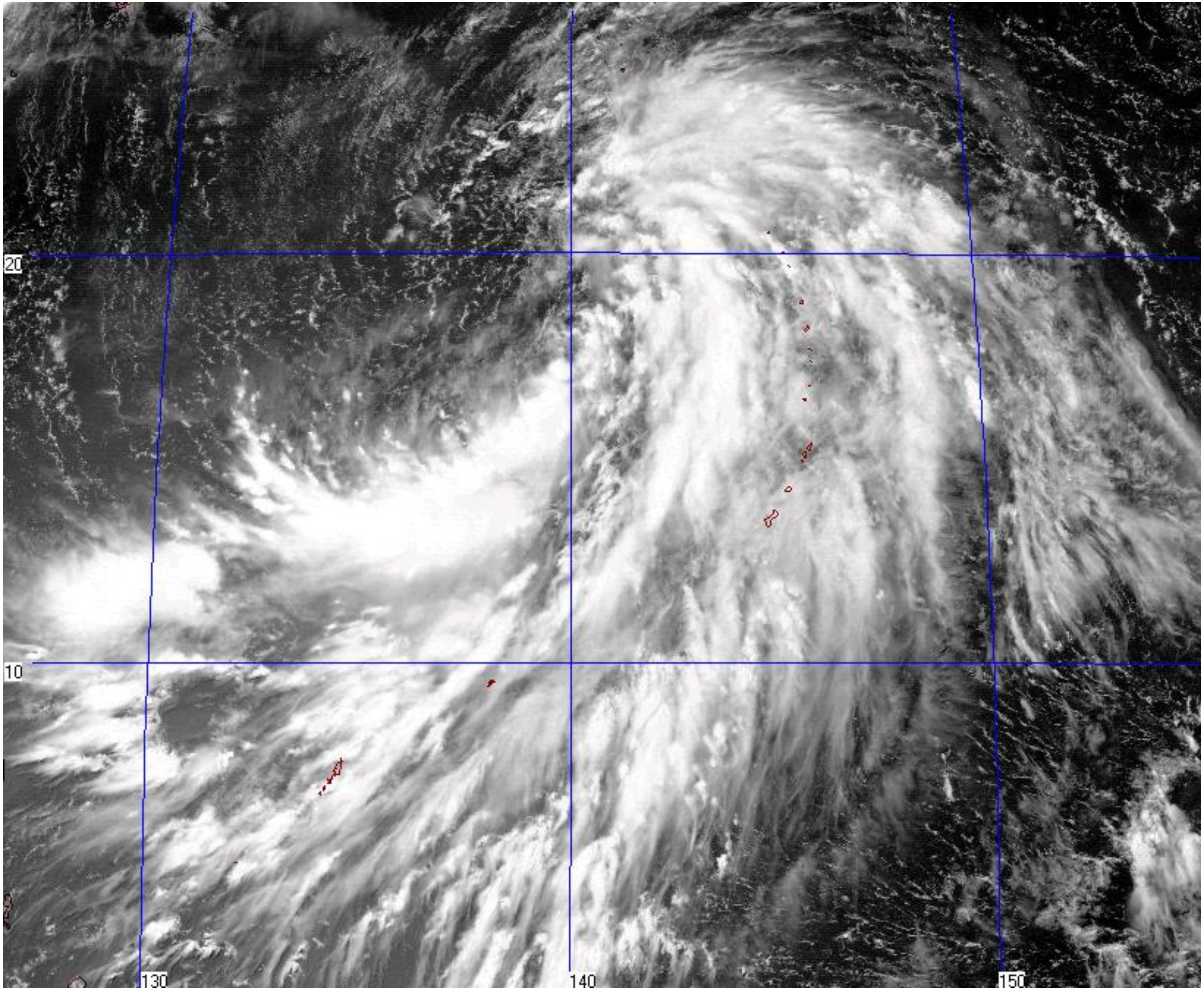


MONSOON DEPRESSION



MONSOON GYRE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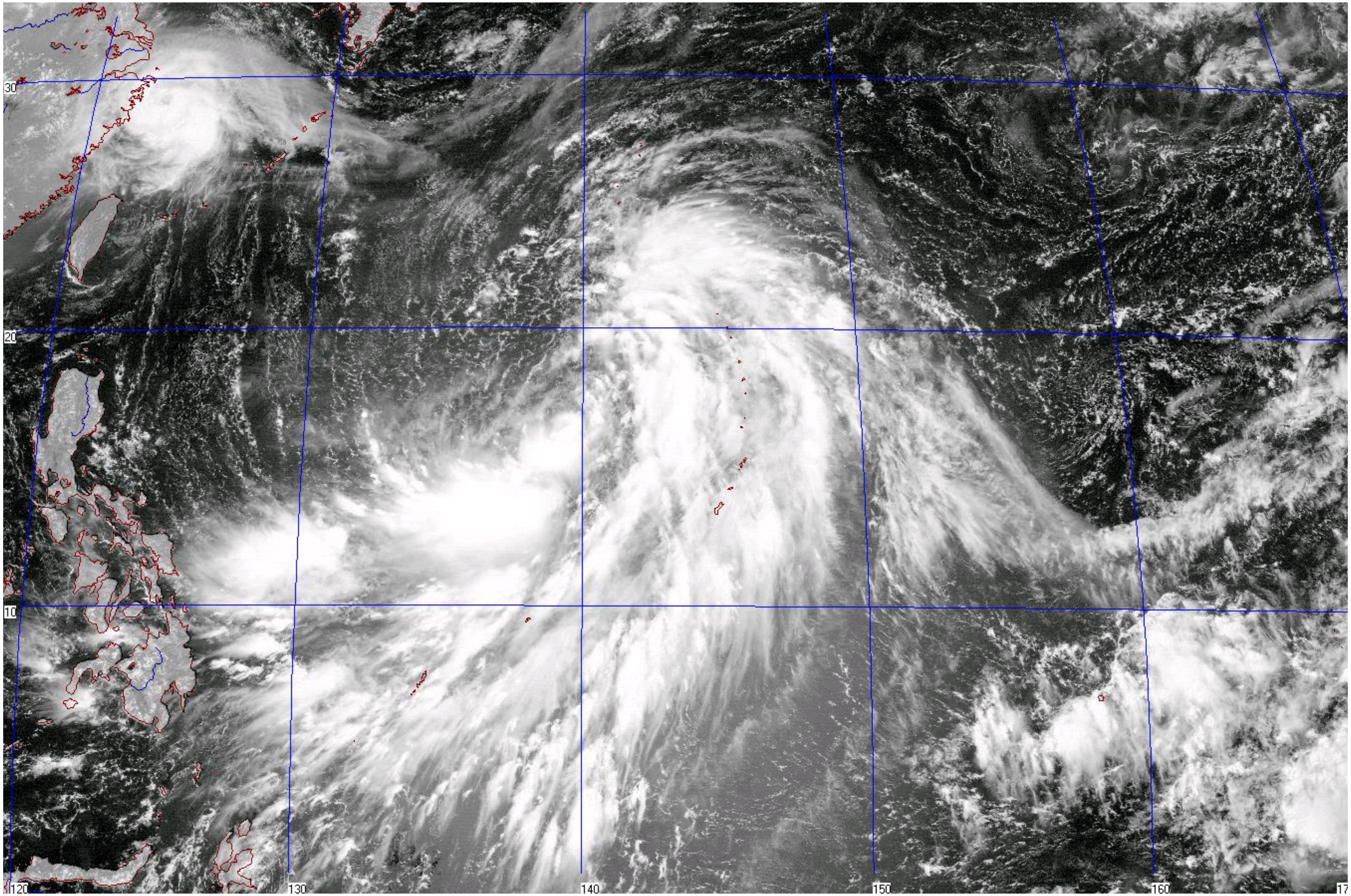
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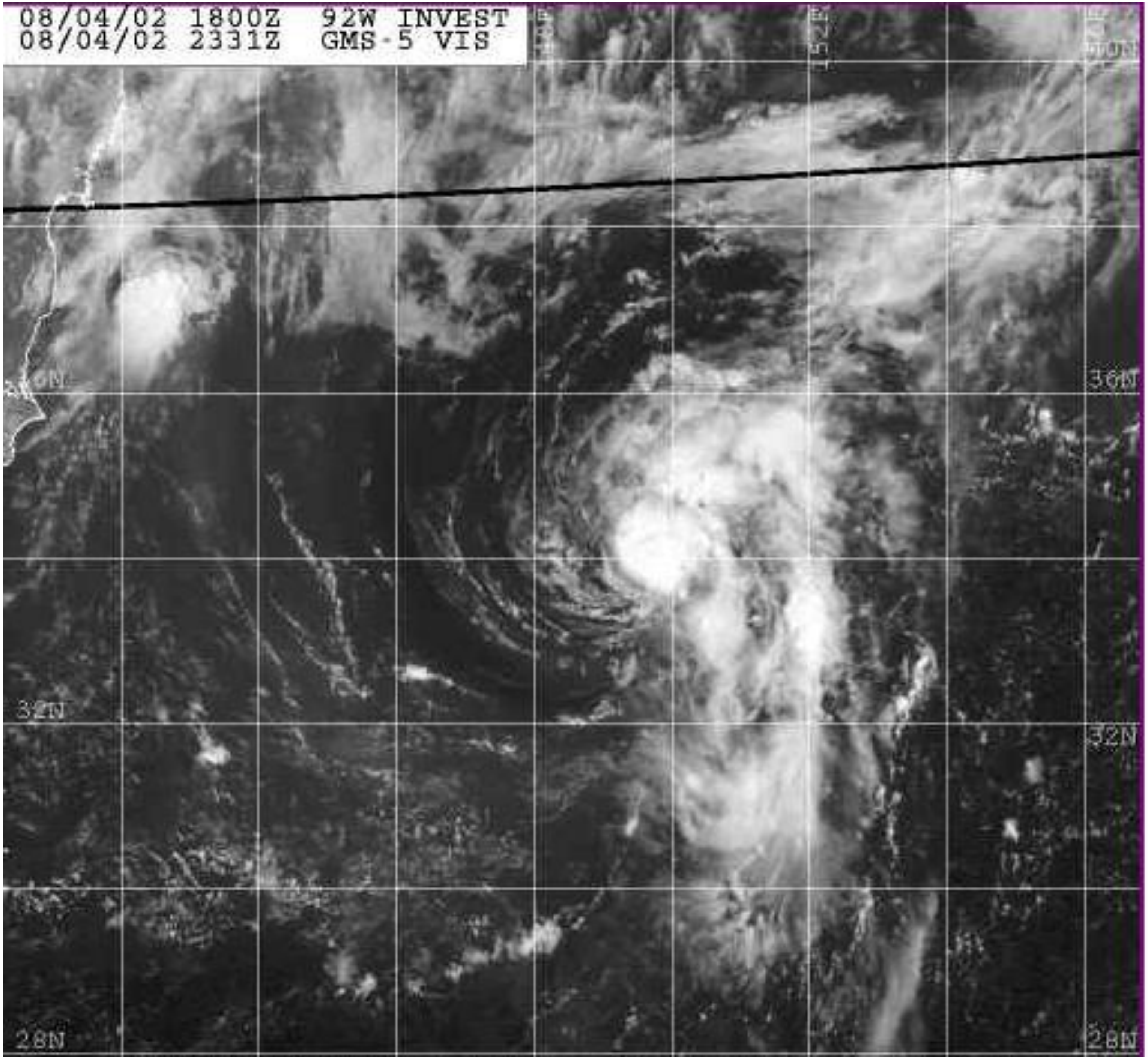
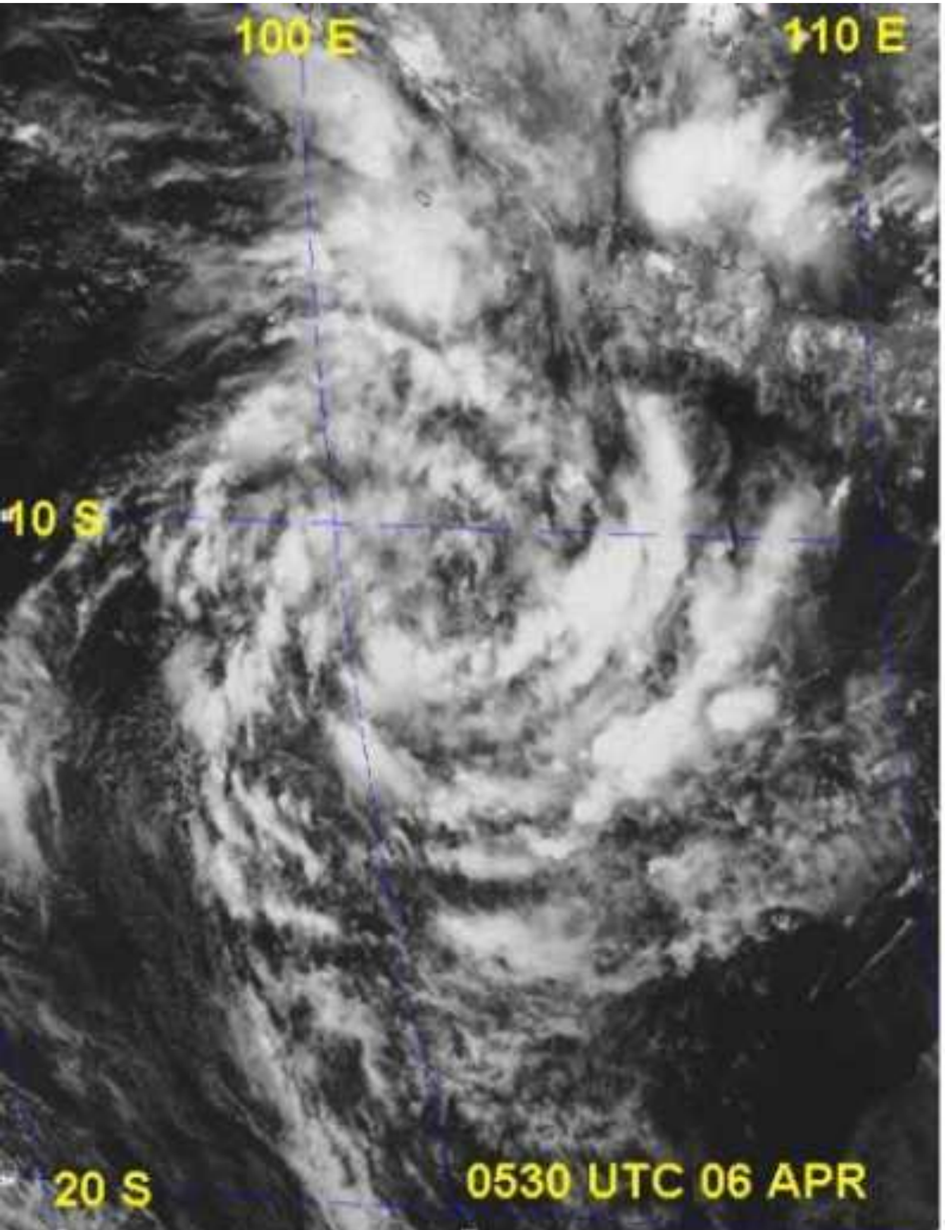

08/04/02 1800Z 92W INVEST
08/04/02 2331Z GMS-5 VIS
36N
32N
32N
28N
28N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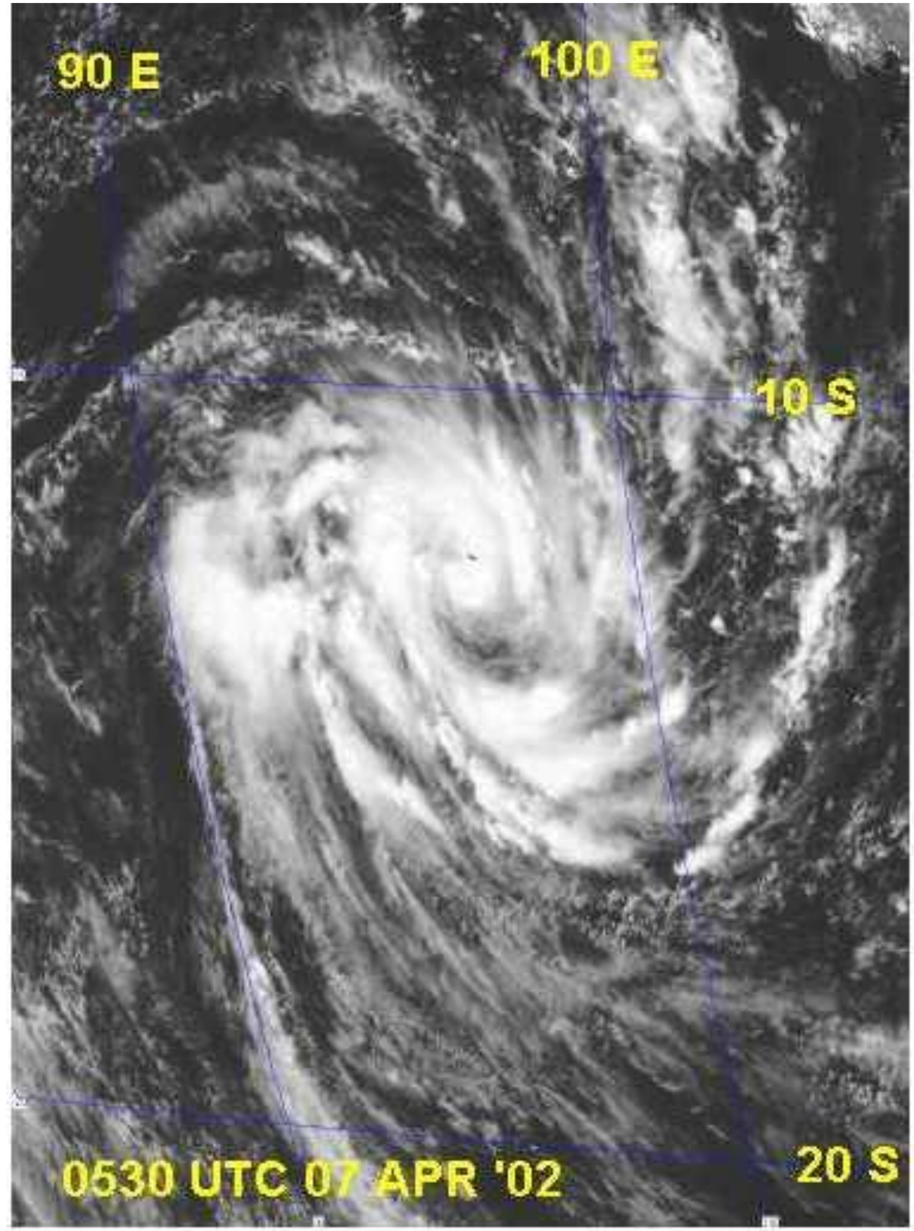
110 E
10 S
20 S
0530 UTC 06 APR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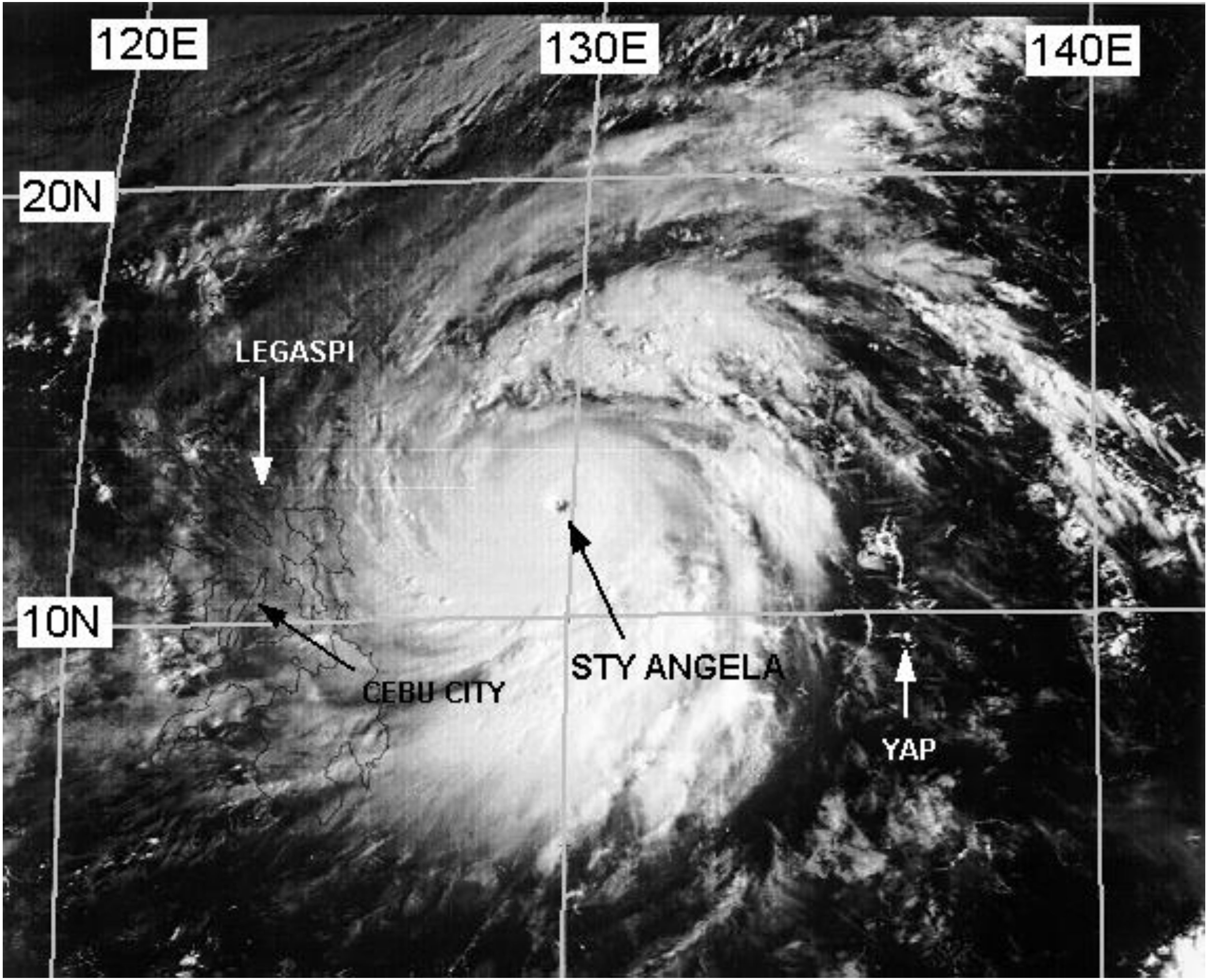
0530 UTC 07 APR '02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STY ANGELA
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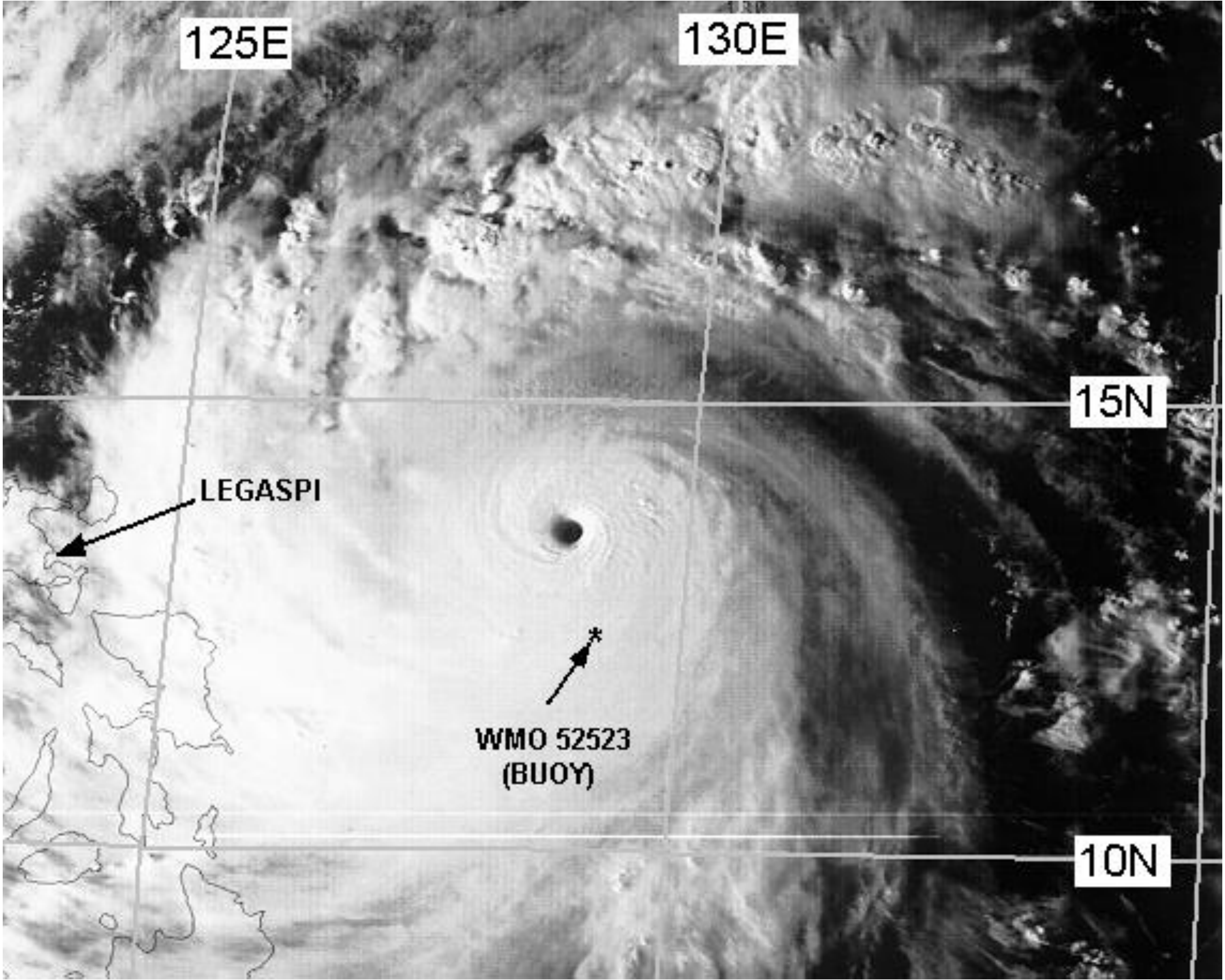
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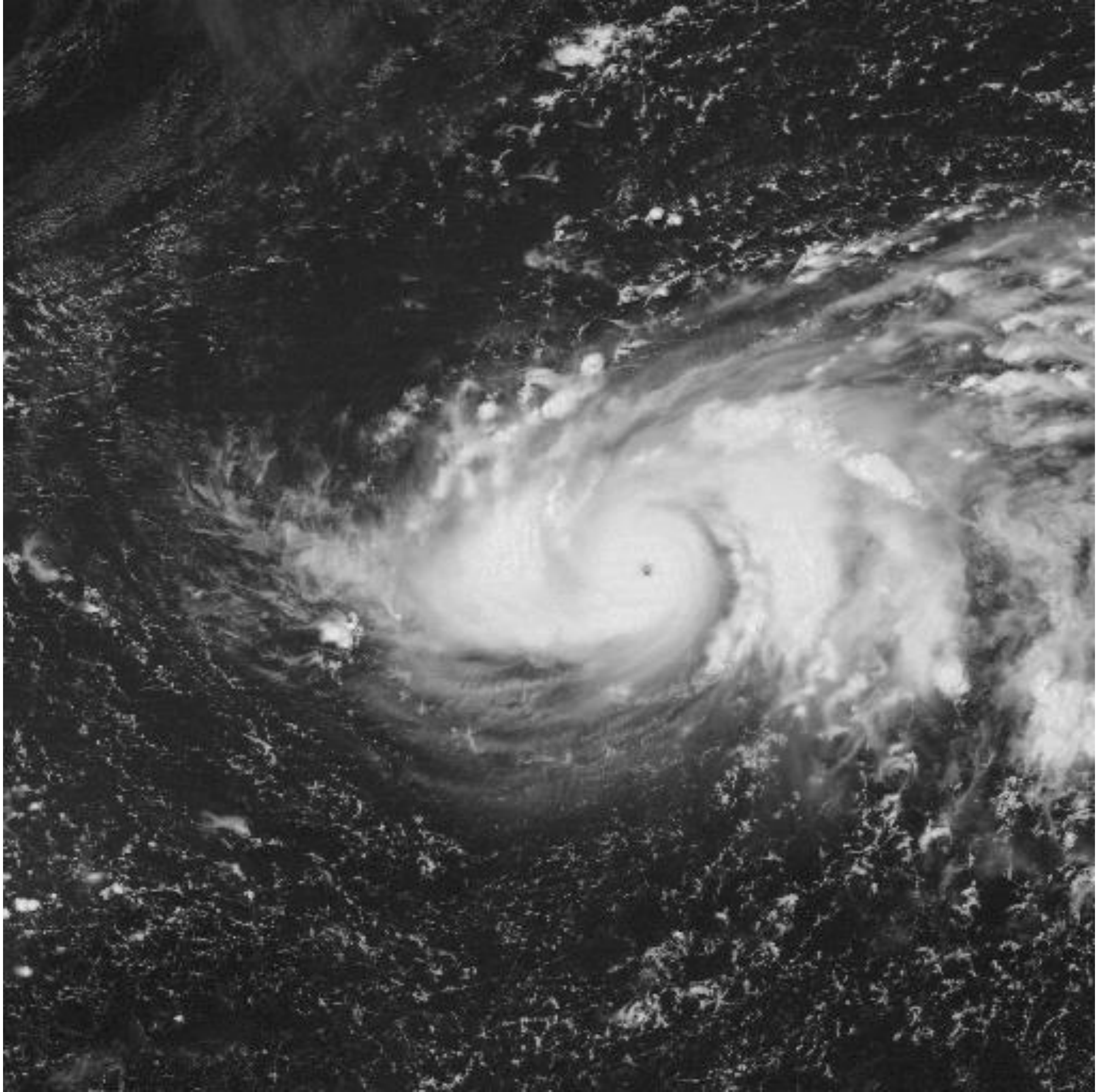

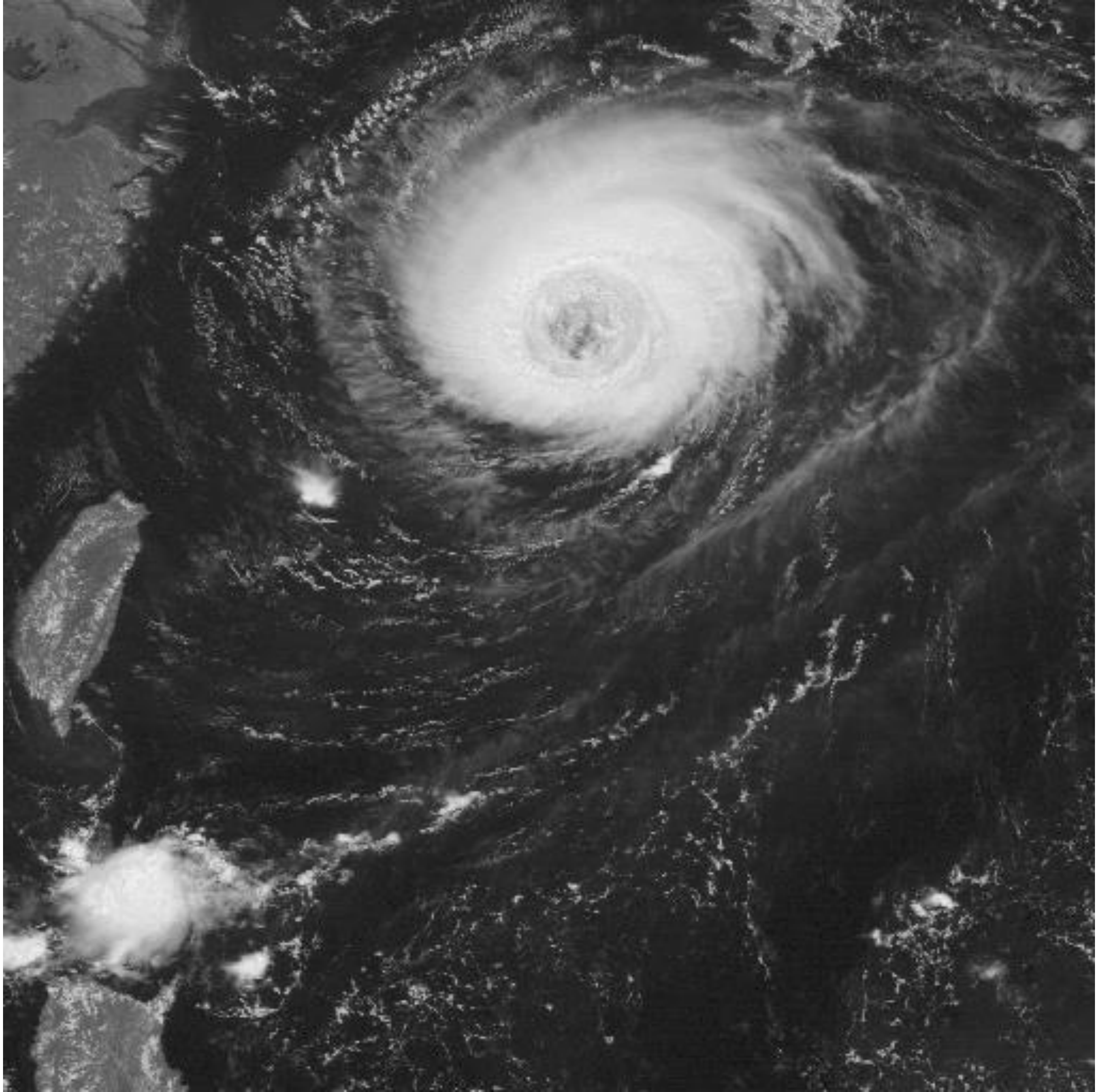

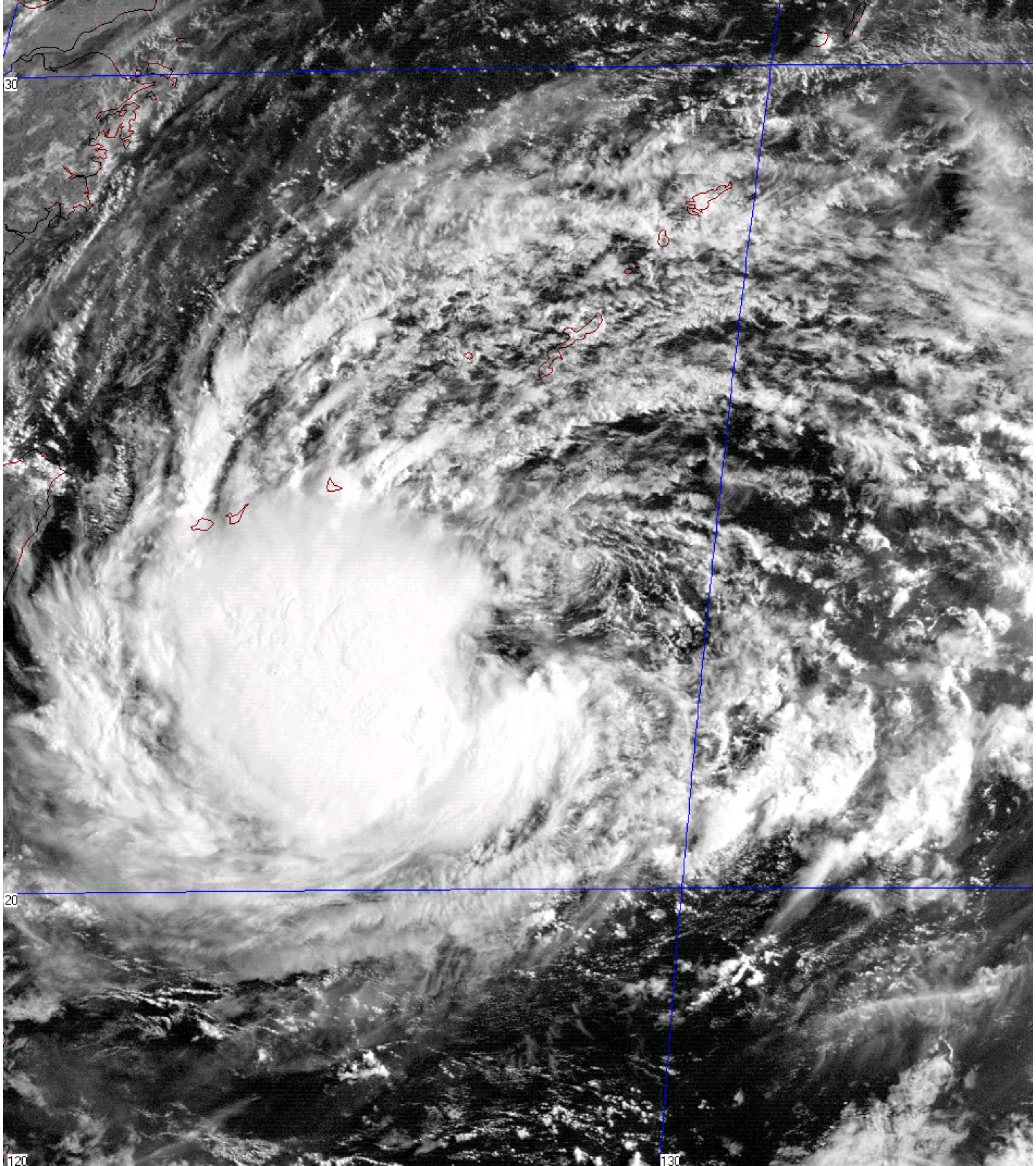
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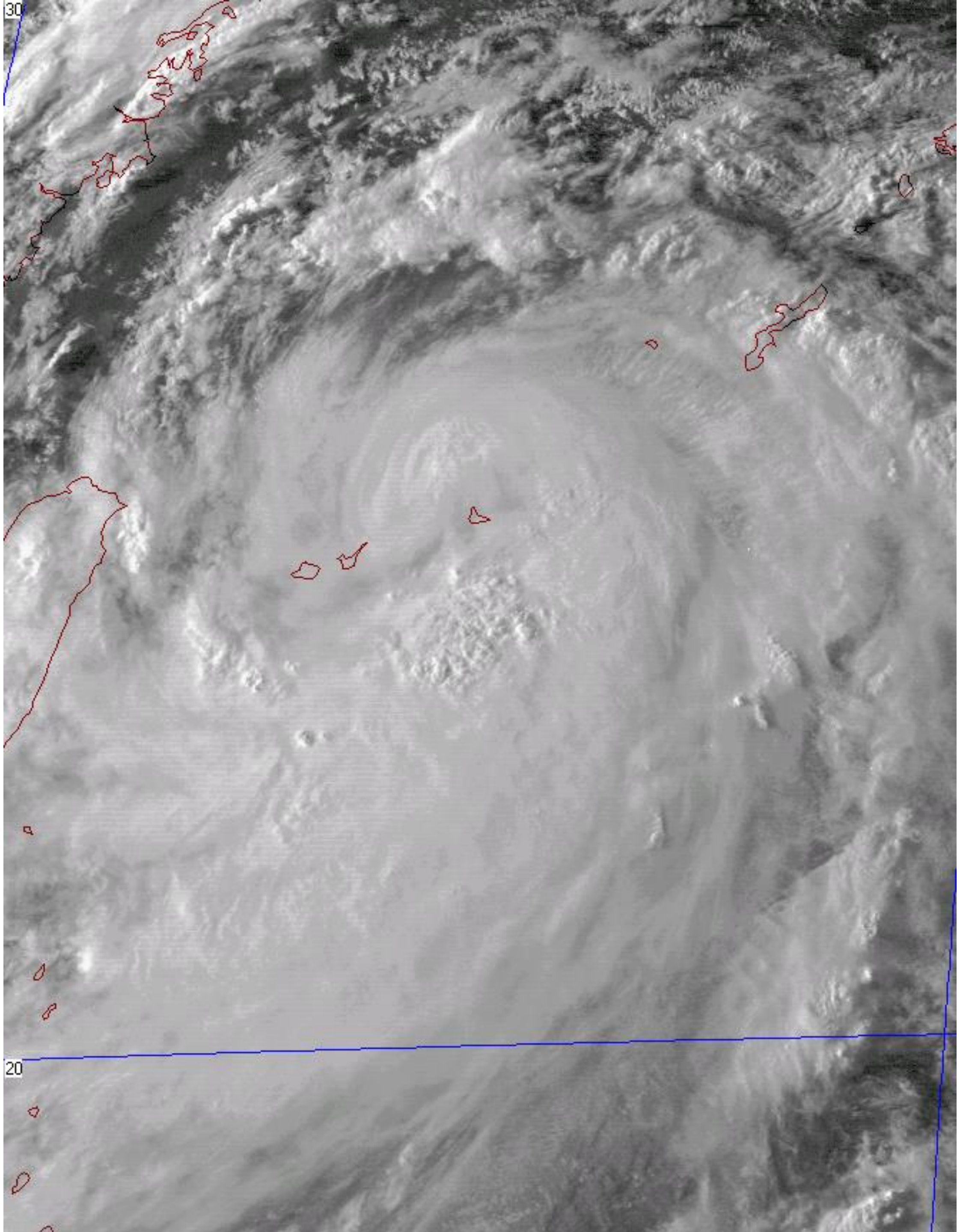
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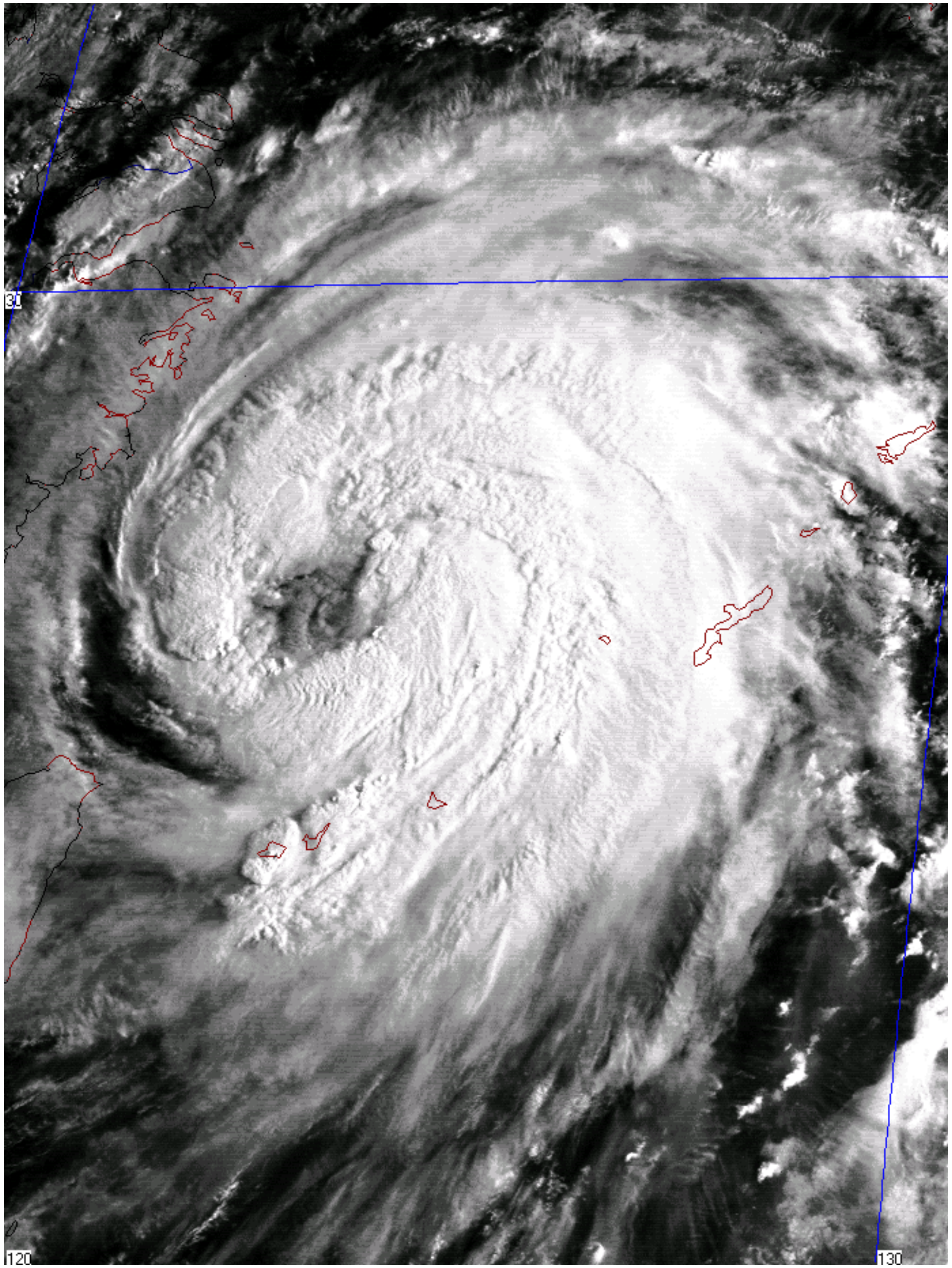
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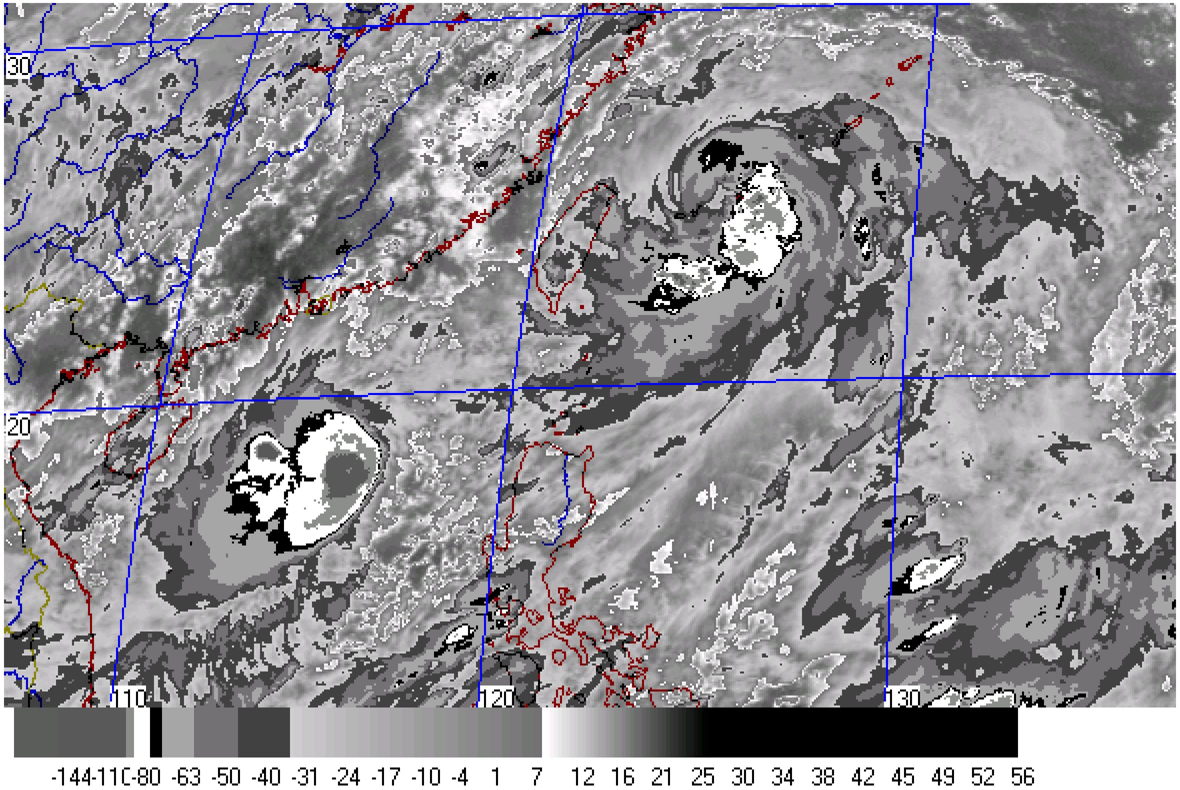
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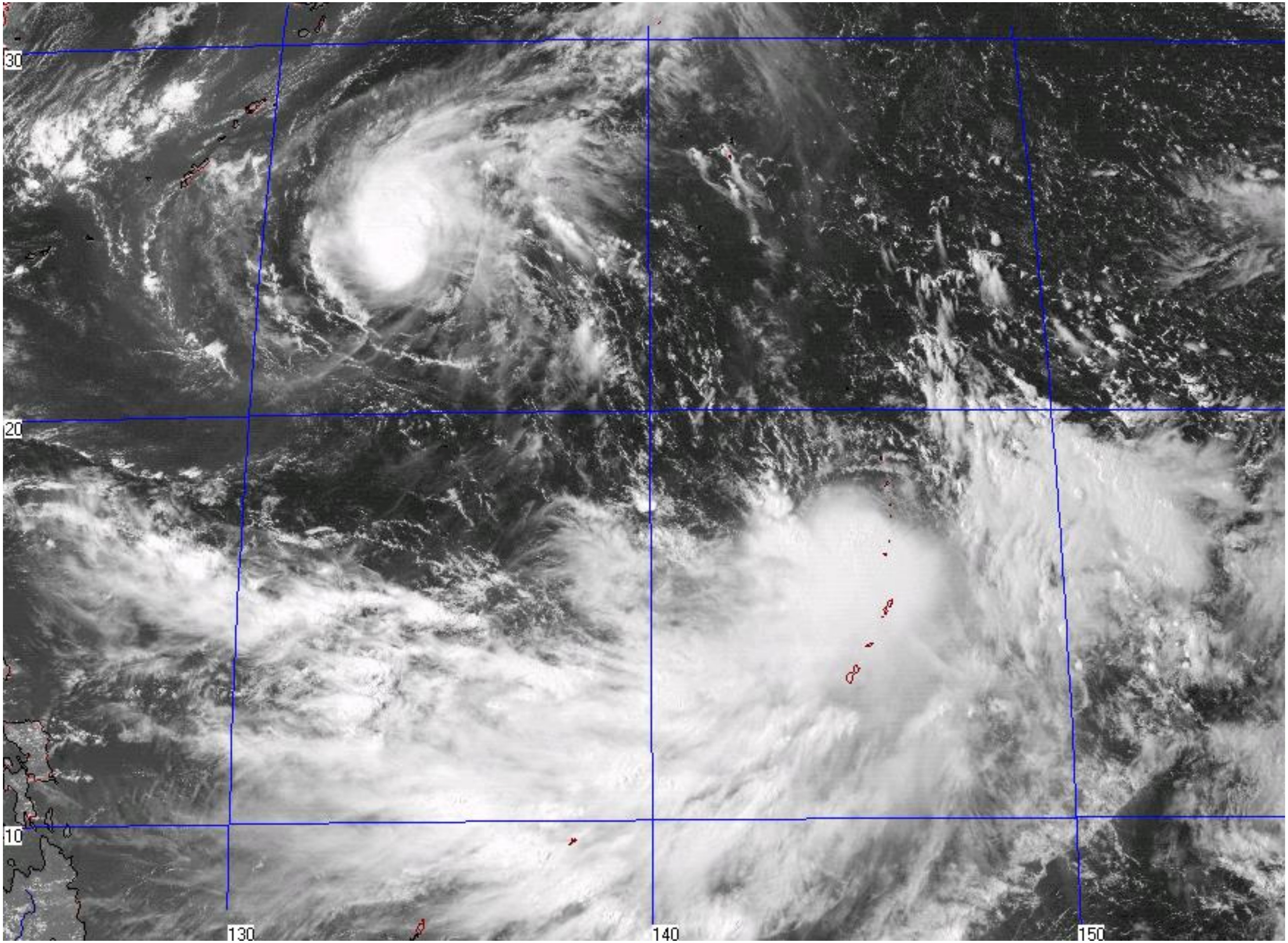
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