# Changes in Tropical Cyclone Behavior Related To Changes in the Upper Air Environment

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August 2007

# Today's Talk

Summary of a 200 page Technical Report

Currently in second draft form for review

and

8 Years of Research

## Tropical Cyclone Behavior

Visible and Infrared Satellite Imagery
Track & Intensity Data from Tropical Centers

Joint Typhoon Warning Center
US National Hurricane Center

## Upper Air Environment

6.7 μm Water Vapor Satellite Imagery
500mb to 300mb Wind & Density Data

Forecast model  Initial and 3 hour forecasts
AVN and GFS  models

Examined and Archived Data
for more than

400 Tropical Cyclones

World Wide

1999 through 2005

# EVENTS

## Storm Behavior

Right Turns ---------- 153 Events
Left Turns ---------- 79 Events
Eye Structure Changes ----- 47 Events
Intensification Going East - 21 Events
Demise ---------- 33 Events
Early Storm Structure -------19 Events
Lift Out ---------- 9 Events

Storm Behavior Events 361

## Environmental Changes

Ridge Rolls ---------- 120 Events
Base Surges ---------- 73 Events
Dry Air Effects ---------- 50 Events
Adjacent System Changes - 76 Events
DZ Formation ---------- 34 Events
Inside Boundaries ----------23 Events

Environmental Change Events 376

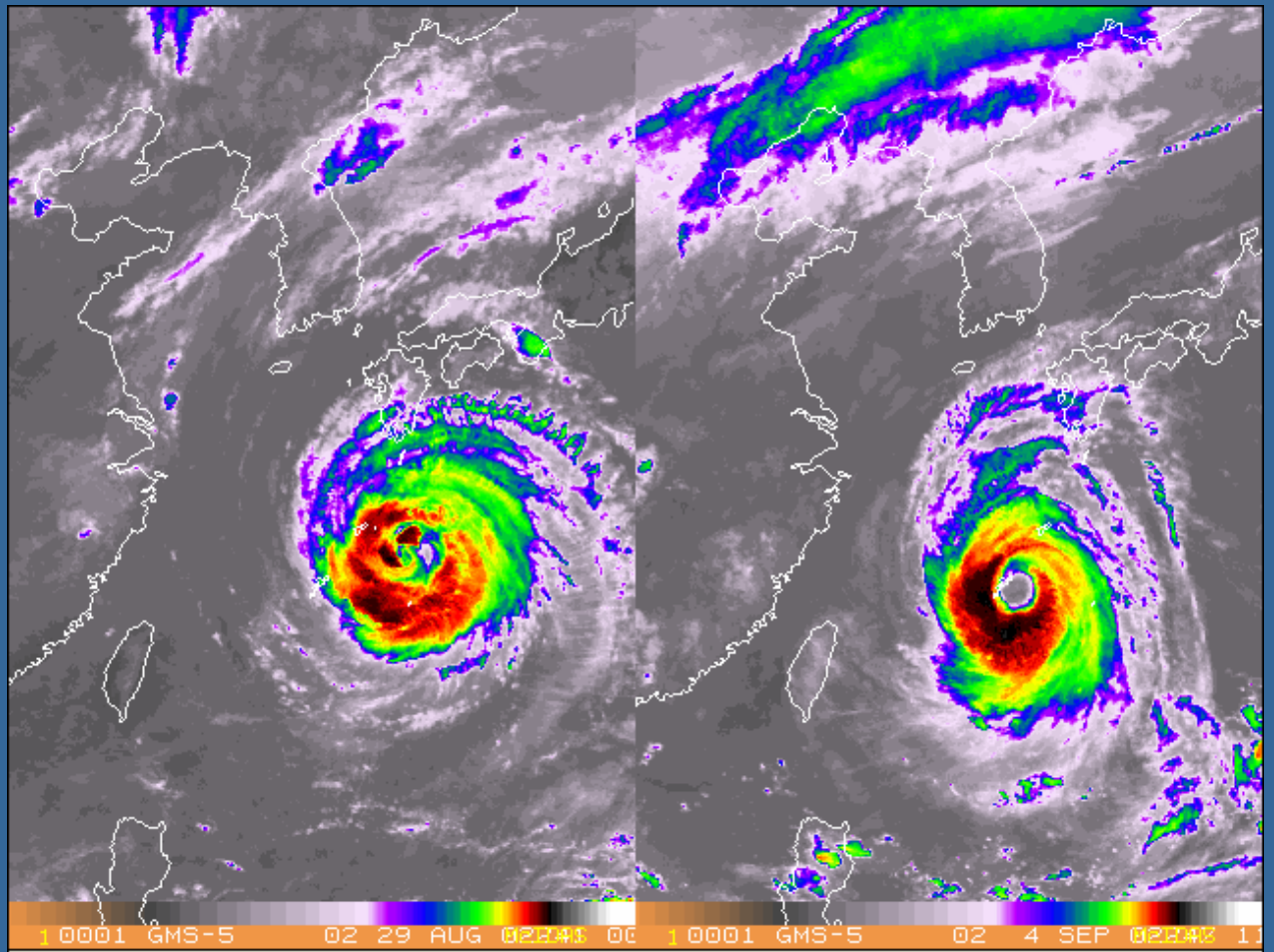
Total Number of Events: 737

Event Categories were defined in 2002. Storm weakening and intensification are well addressed in the context of other events.

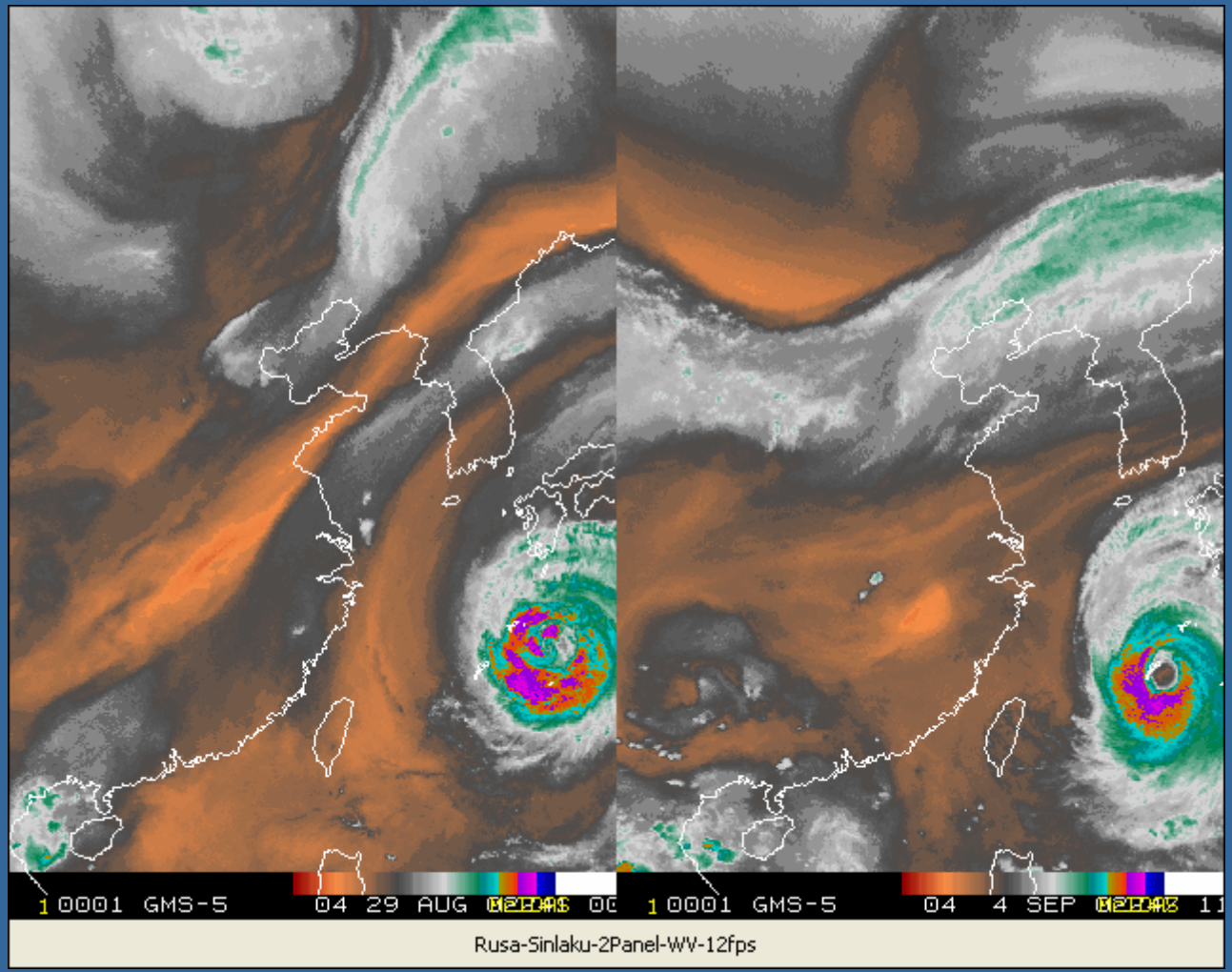
# An Introduction

## Rusa - Sinlaku Comparison

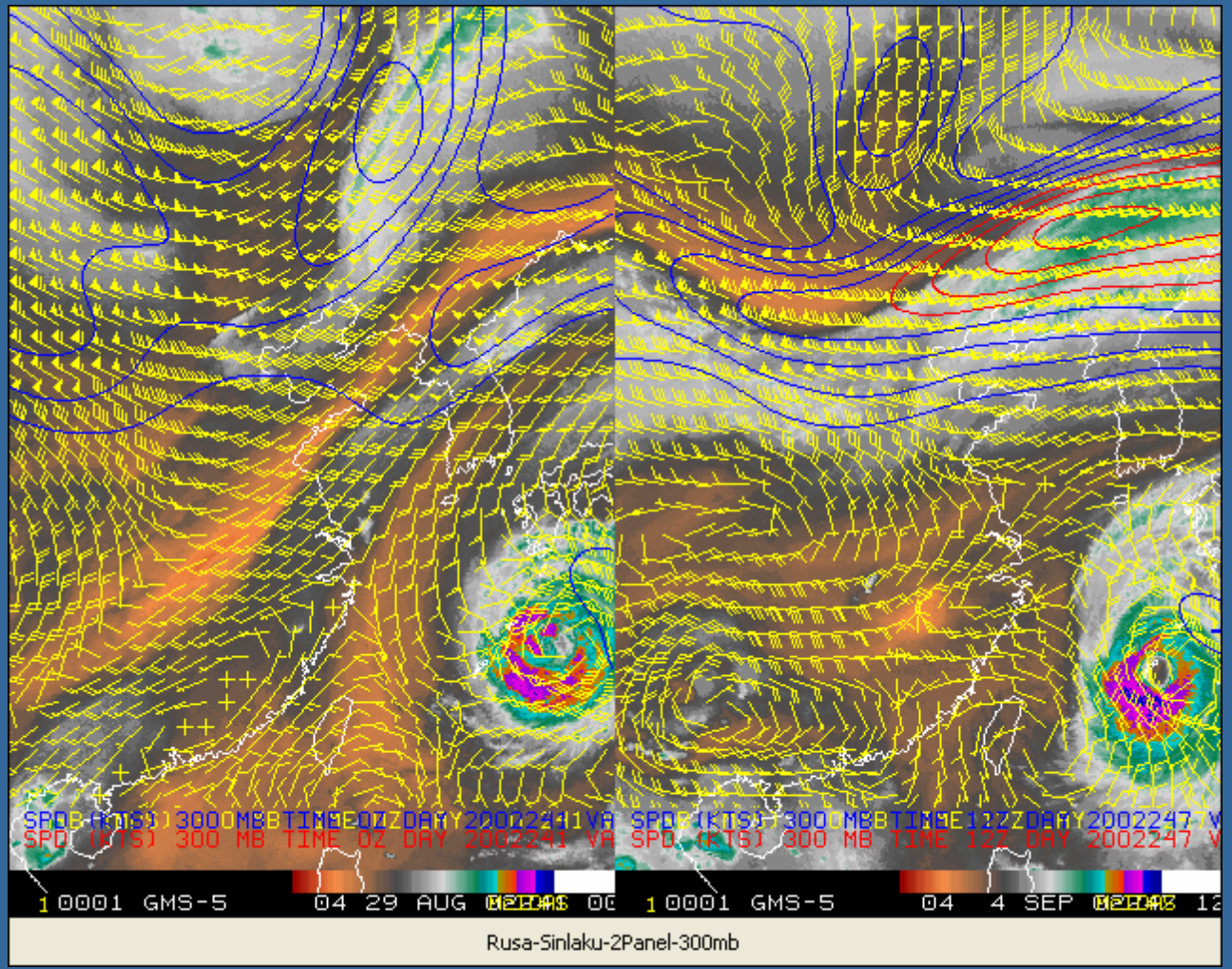
Two Different 48 Hour Periods in late August and early September 2002 about one week apart (6.5 days)




WP-02 Rusa IR Loops WP-02 Sinlaku




Typhoon Rusa Water Vapor Loops Typhoon Sinlaku




Rusa 300mb AVN Winds Loops Sinlaku

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"DZ" = "Deformation Zone" ------ the stretching axis of a col in the wind field

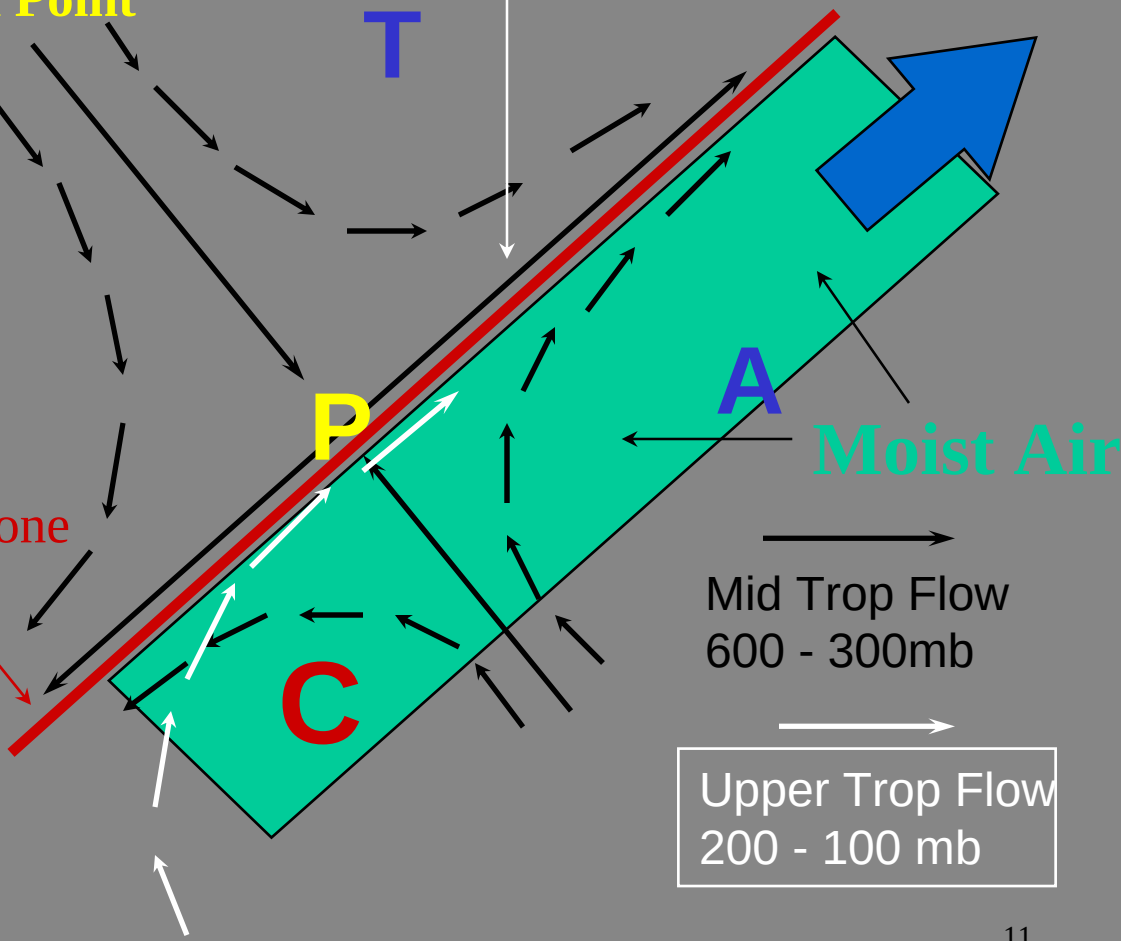
26 Formations 2 No Development 6 Intensification (storm already present)

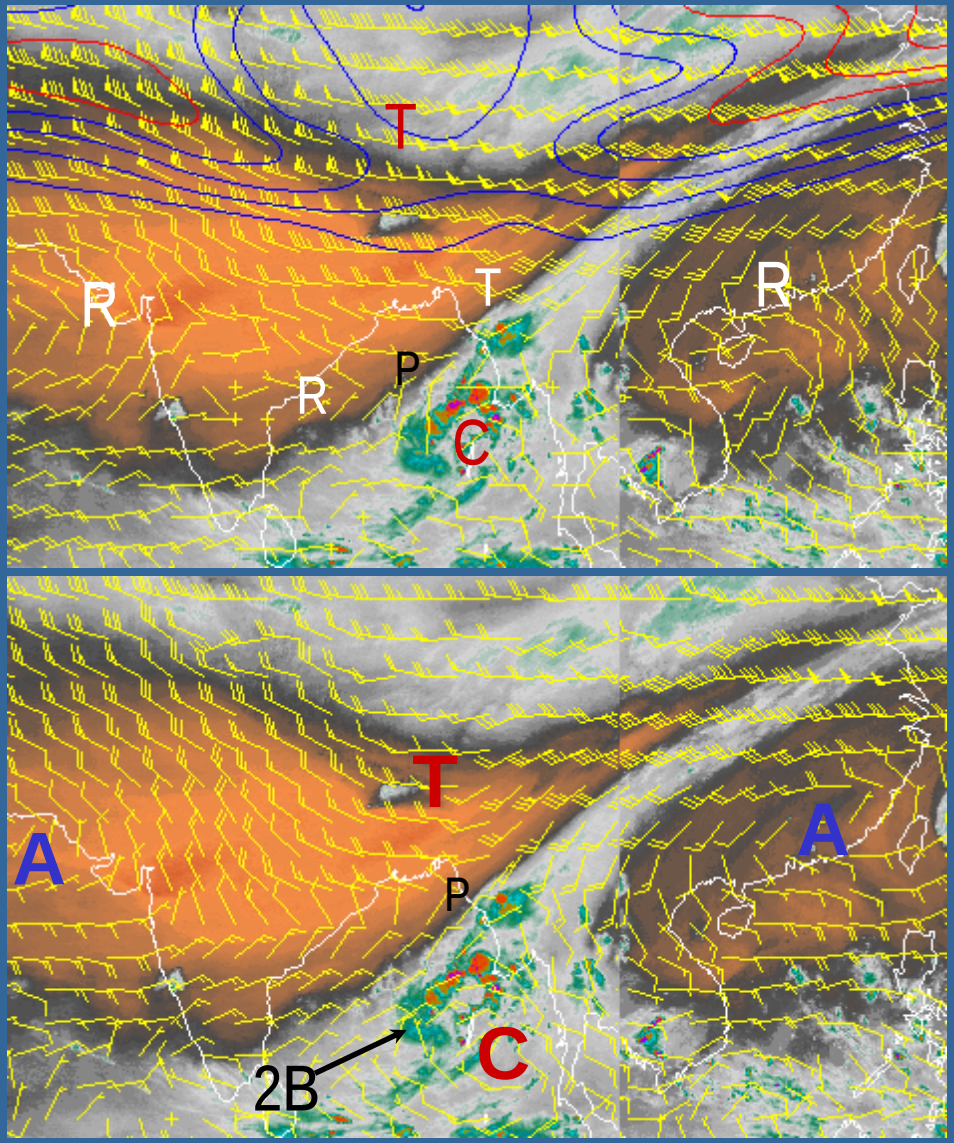
# DZ Development

DZ=Stretching Axis of Col

5-01

P = "Division Point"






300mb Winds

Merged Views from Meteosat 5 and GMS Satellites
1800z 24 October 00

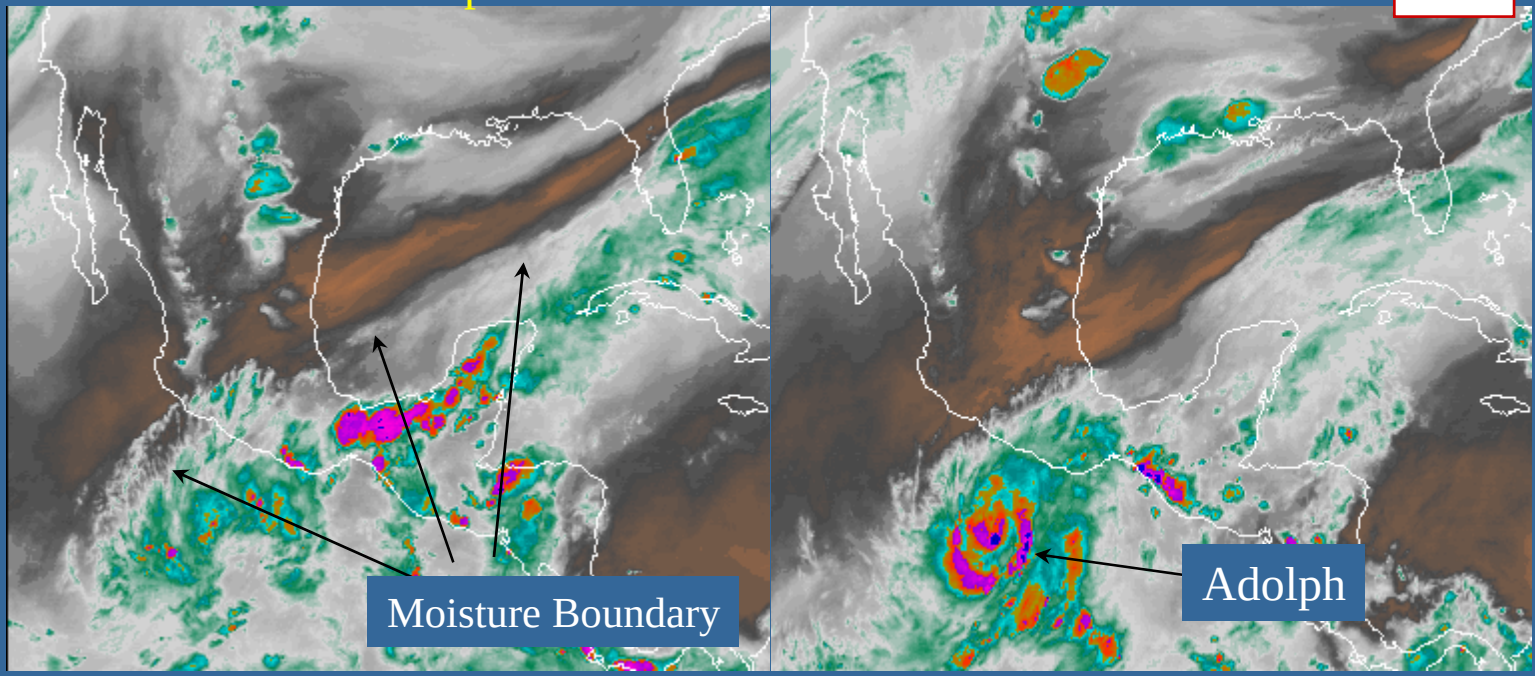
Formation of Cyclone 2B Bay of Bengal

500mb Winds

# Formation Adolph

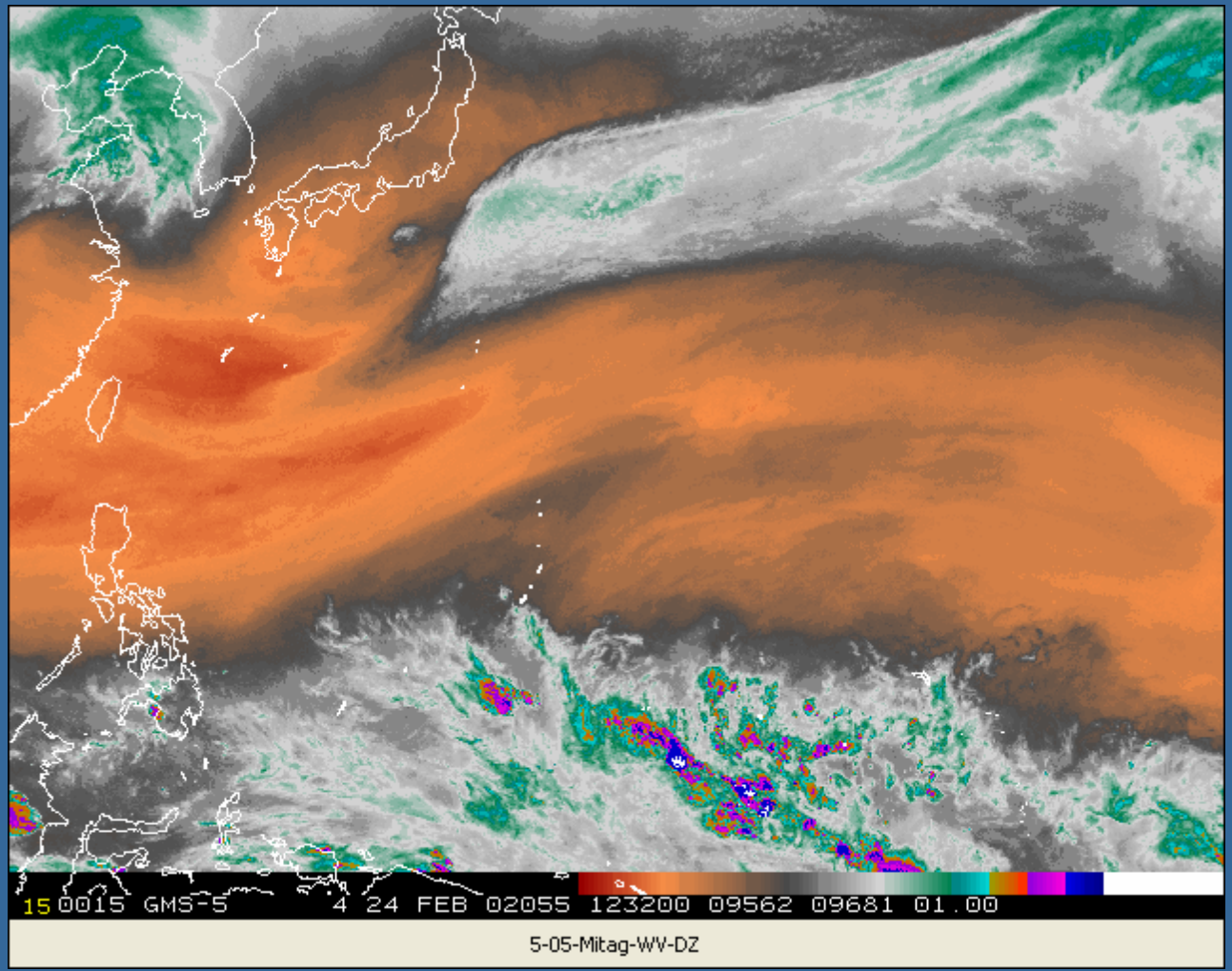
EP-01 Adolph

5-03

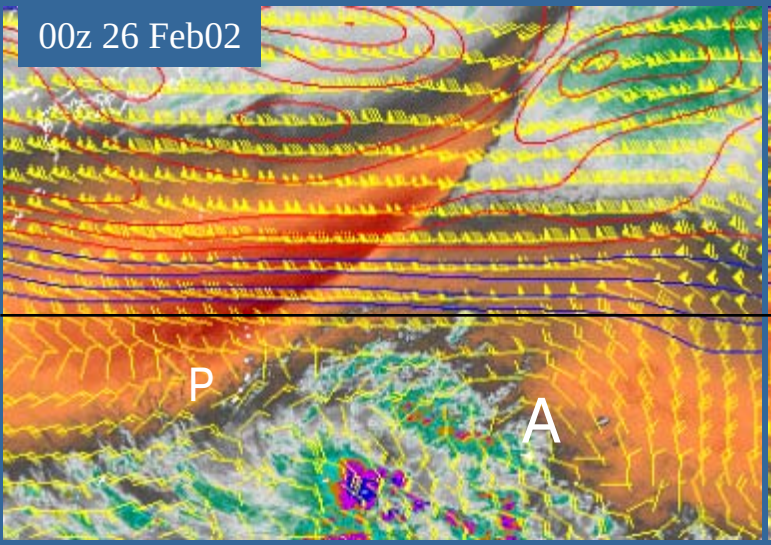


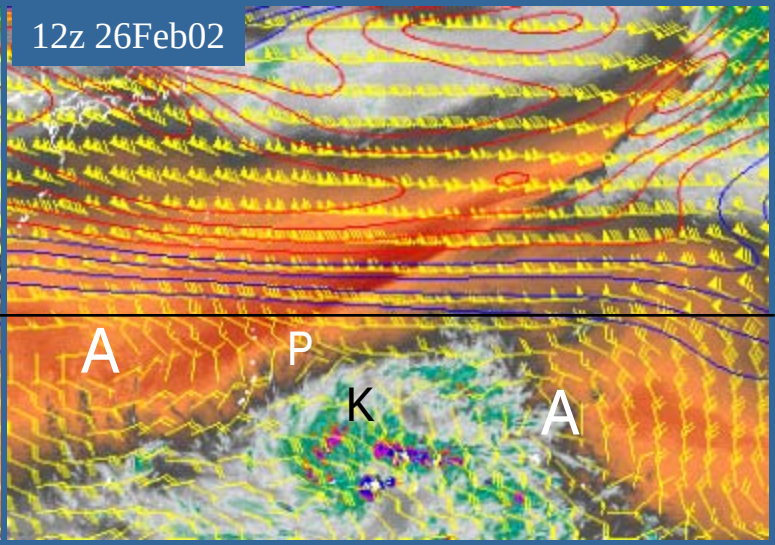

0015z 26 May 01 6.7 micron Water Vapor 0015z 27 May 01

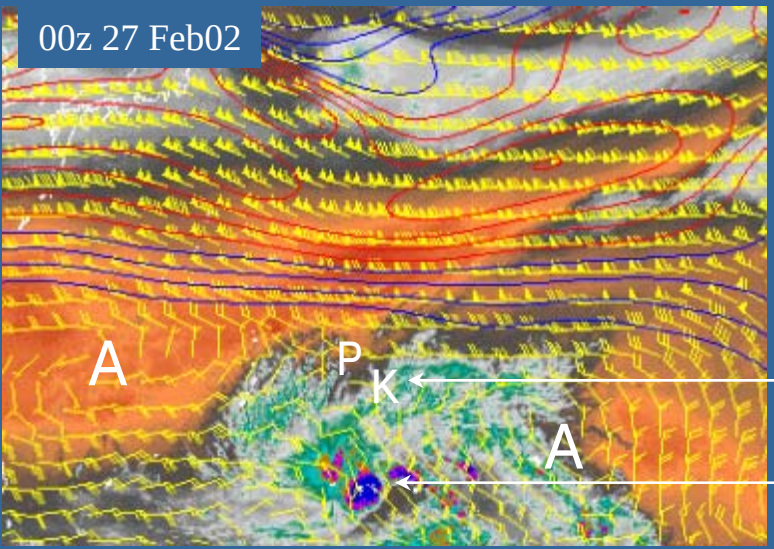
Drying with time on NW side of boundary which becomes more distinct & better defined.
WV Loop showed significant drying over Mexico and moving SW off shore
Adolph formed at 40 knots intensity at 00z 27 May 01.




5-05 WP-02 Mitag Water Vapor 1232z 24 Feb - 0032z 26 Feb 02




5-06

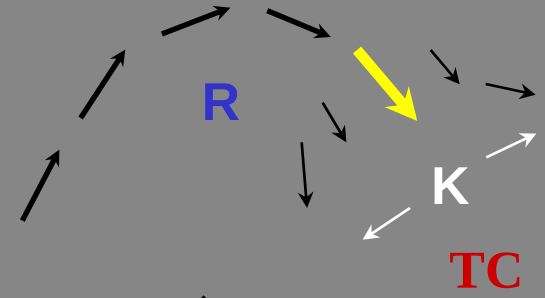
WP-02 MITAG

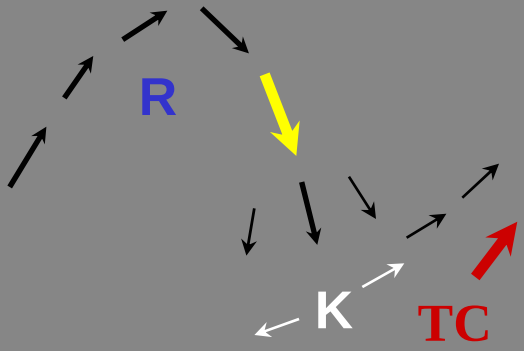
300mb AVN Winds

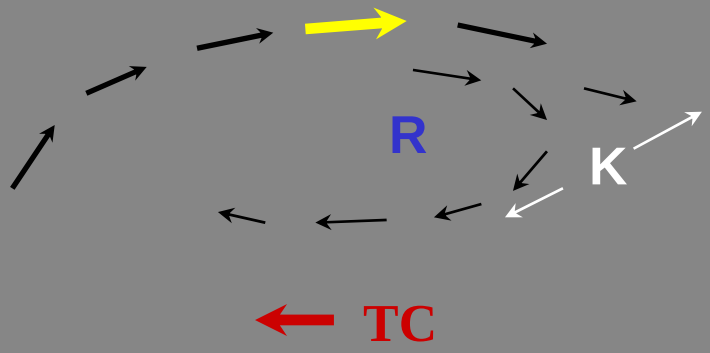
00z 26 Feb 02 Top-Left panel
Same time as last panel Figure 5-05

COL Zone K

Mitag Intensity 30 knots
Named 6 hours later




1. **R**idge holds in place, sending sequential speed maxima generally toward the same location. The **TC** is likely to meander and weaken, or be destroyed

2. The **R**idge retrogrades ; the next speed maximum digs to the west of the **TC**. The **TC** is likely to turn right in advance of the newly retrograded trough. It may intensify moving NE; but, weakening is most likely

3. **R**idge "ROLLS OVER" eastward on the poleward side of the **TC**.
The **TC** **is** likely to turn left, or accelerate westward and intensify.

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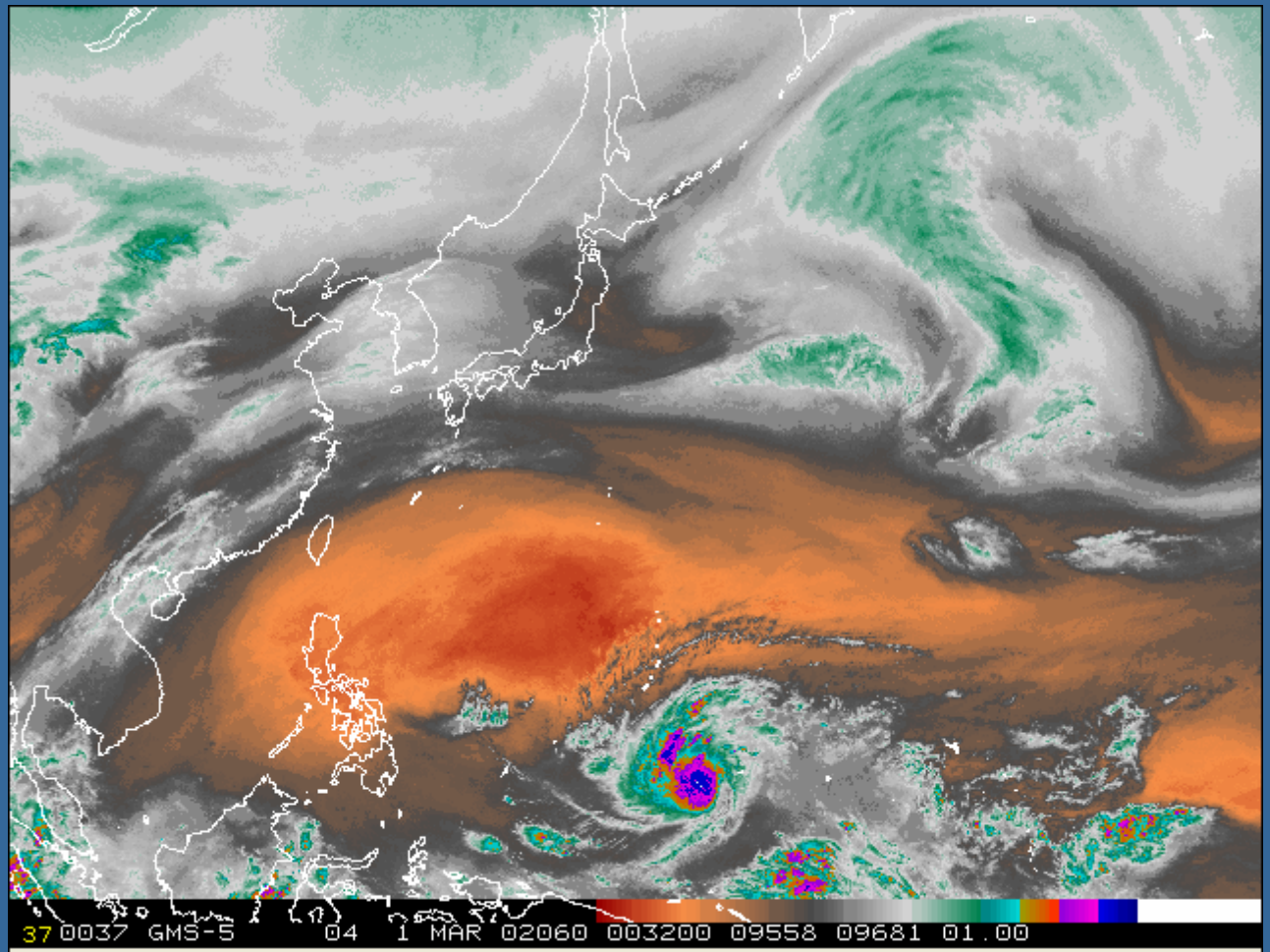
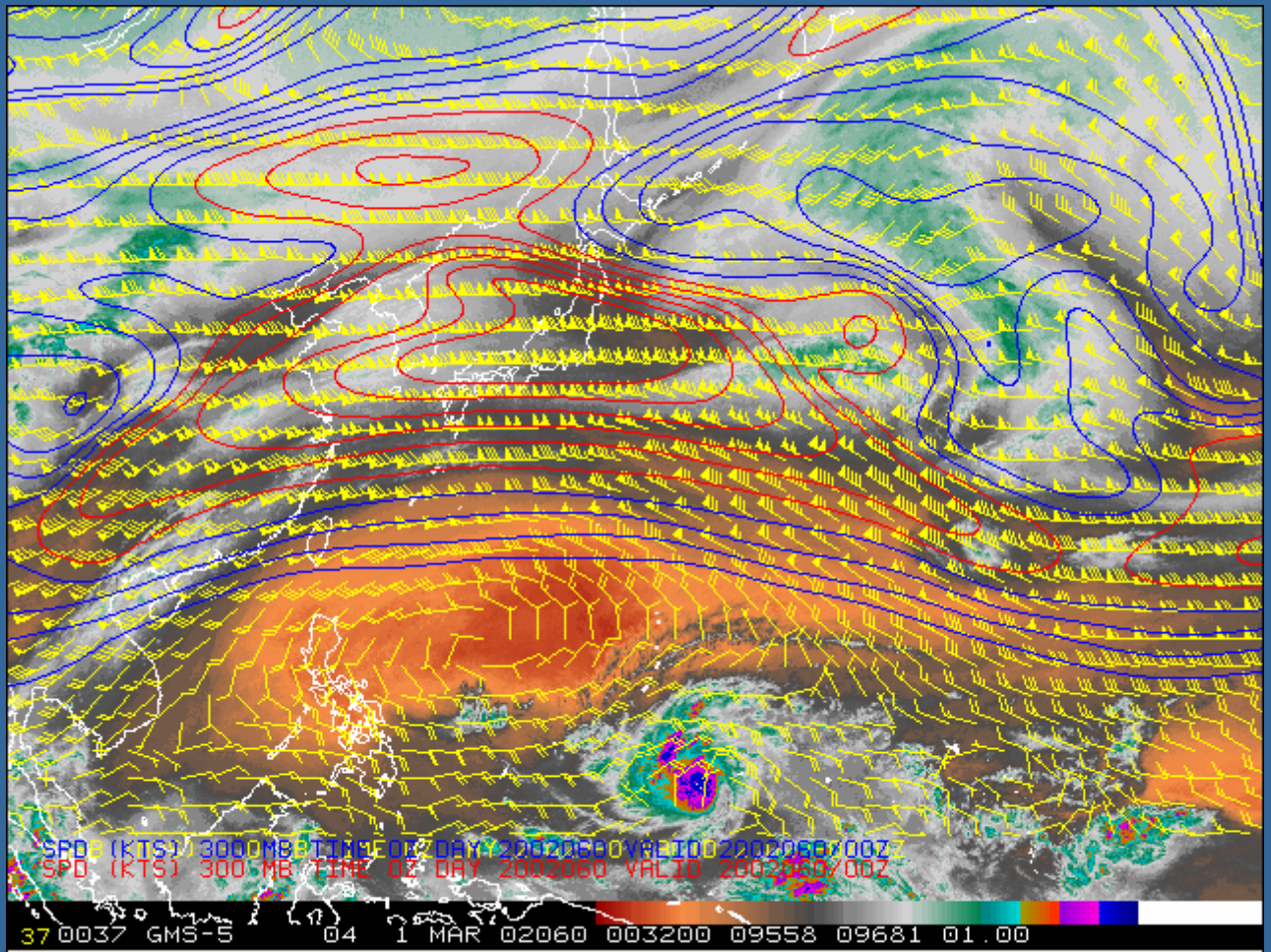
"Ridge Roll" shortened from the original "Ridge Roll Over" The term originated from the appearance on time lapse motion winds or satellite imagery ------ of a giant wheel "rolling over" the storm position.



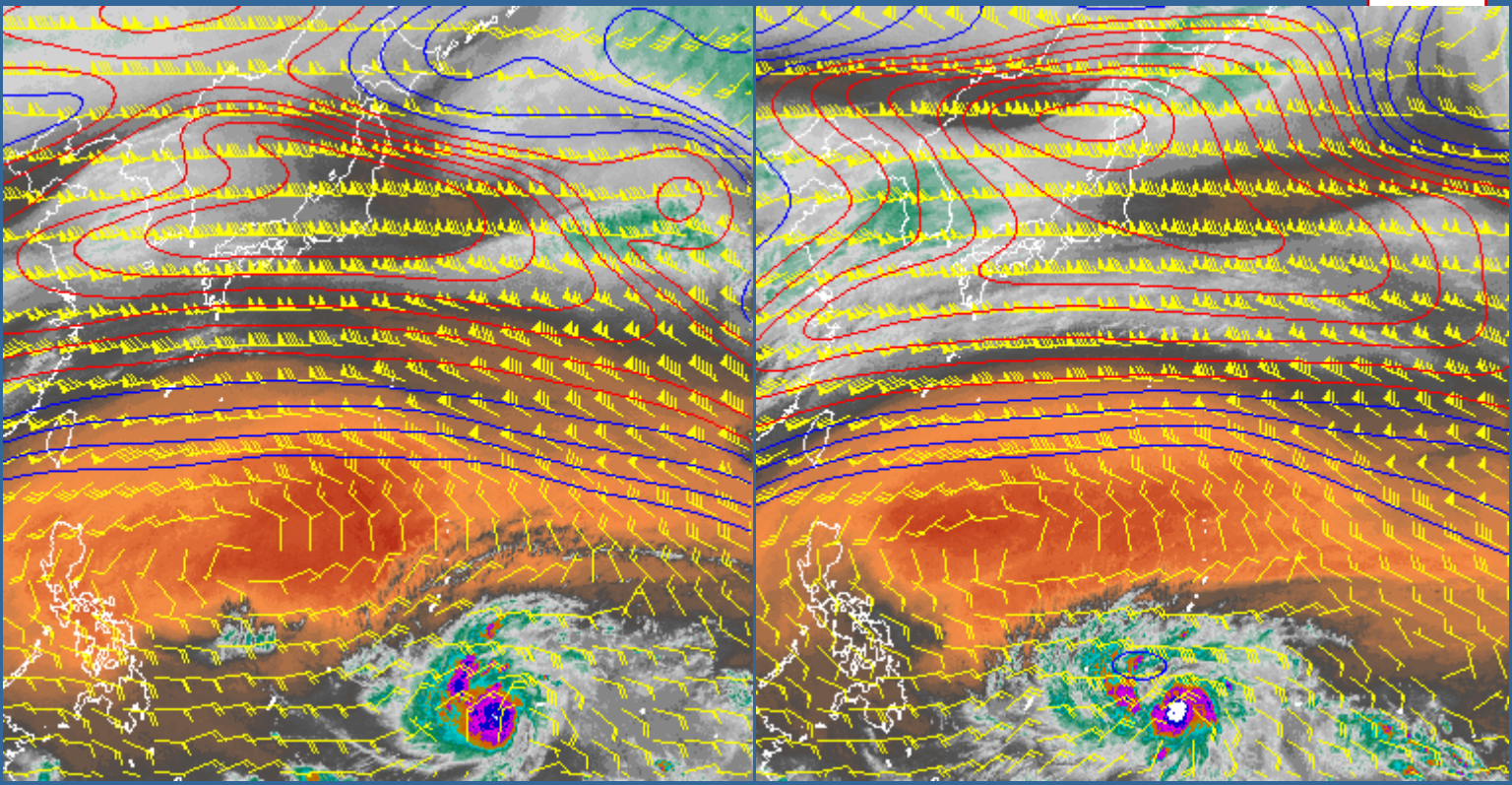

2-01 to 03 Water Vapor Loop 00z 1 March - 00z 3 March 2002




2-01 to 03 300mb AVN Winds 00z 1 March - 00z 3 March 2002

P-1 24 Hours 65 to 70 knots WP-02 Mitag

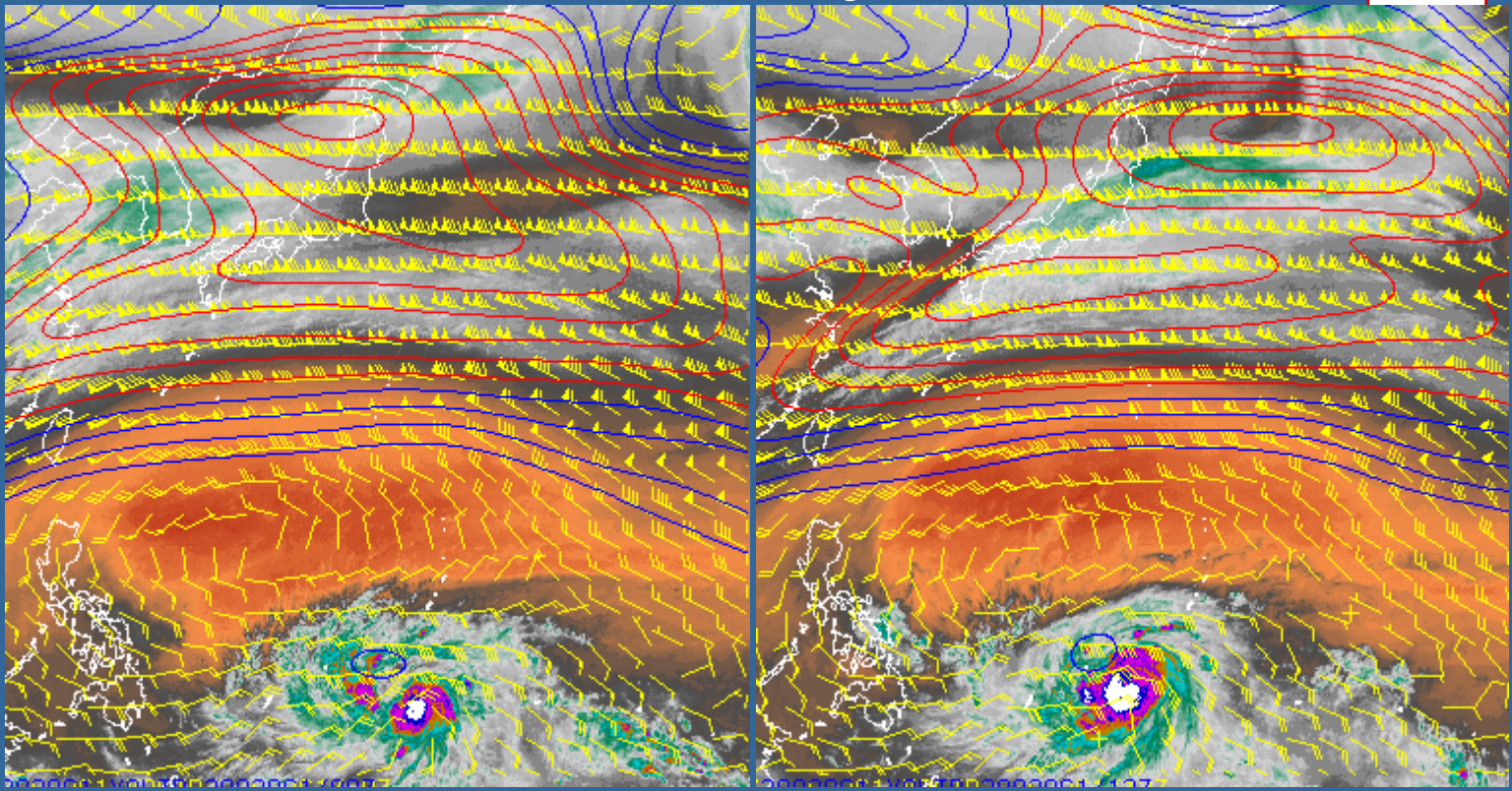
2-01



00z 1 March 02 300mb GFS Winds 00z 2 March 02

P-2 12 Hours 70 to 85 knots WP-02 Mitag

2-02

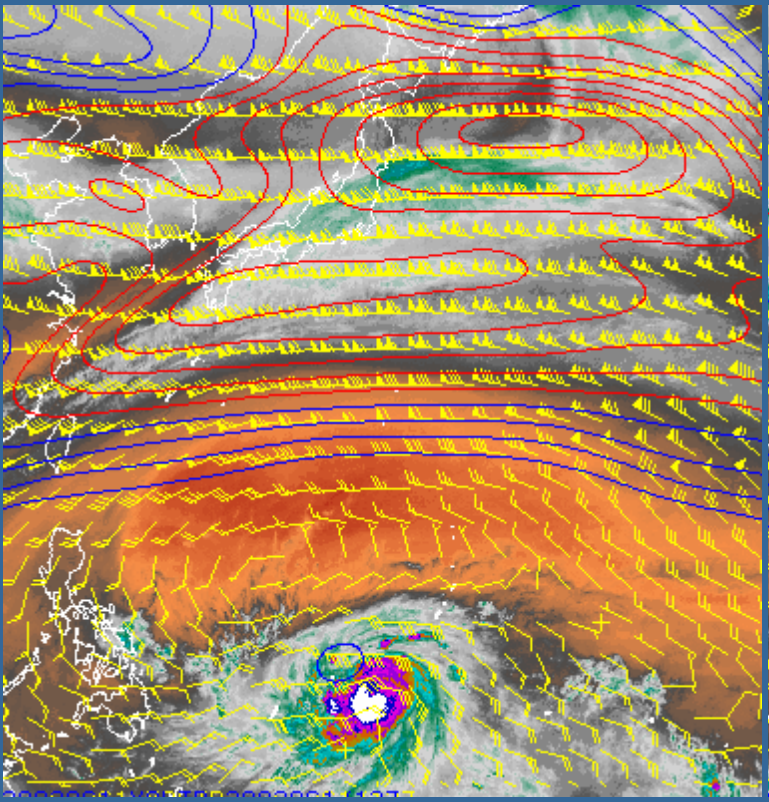


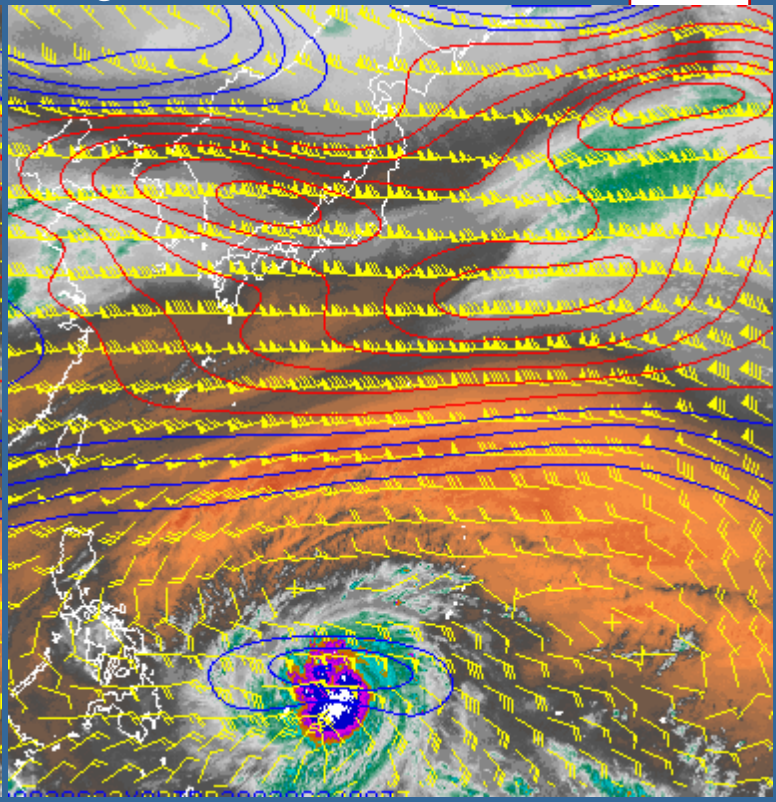
00z 2 March 02 300mb GFS Winds 12z 2 March 02

70 to 85 kts in 12 hours moving 290 degrees

P-3 12 Hours 85 to 100 knots WP-02 Mitag

2-03





12z 2 March 02 300mb GFS Winds 00z 3 March 02

65 to 100 knots intensification entire 48 hour period

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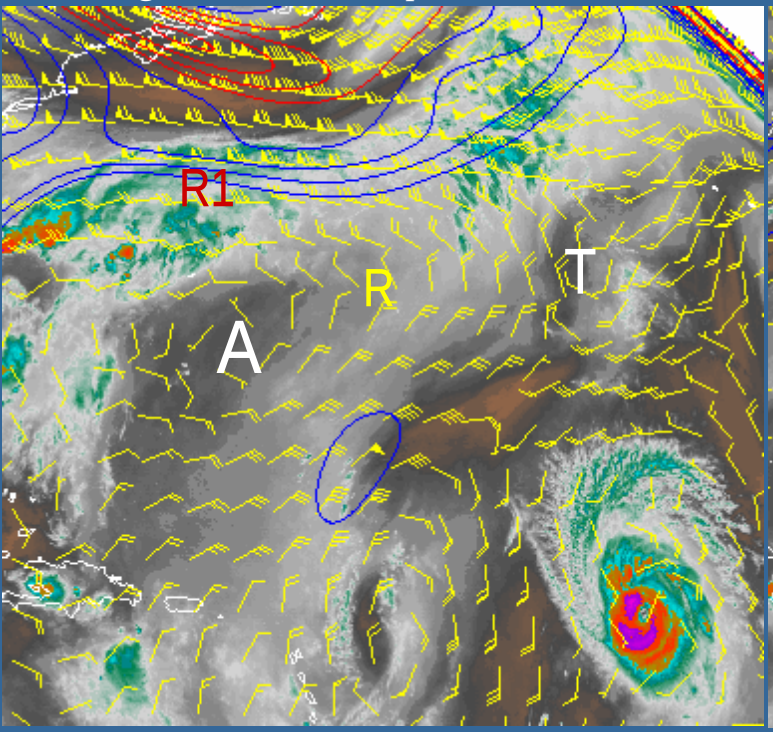
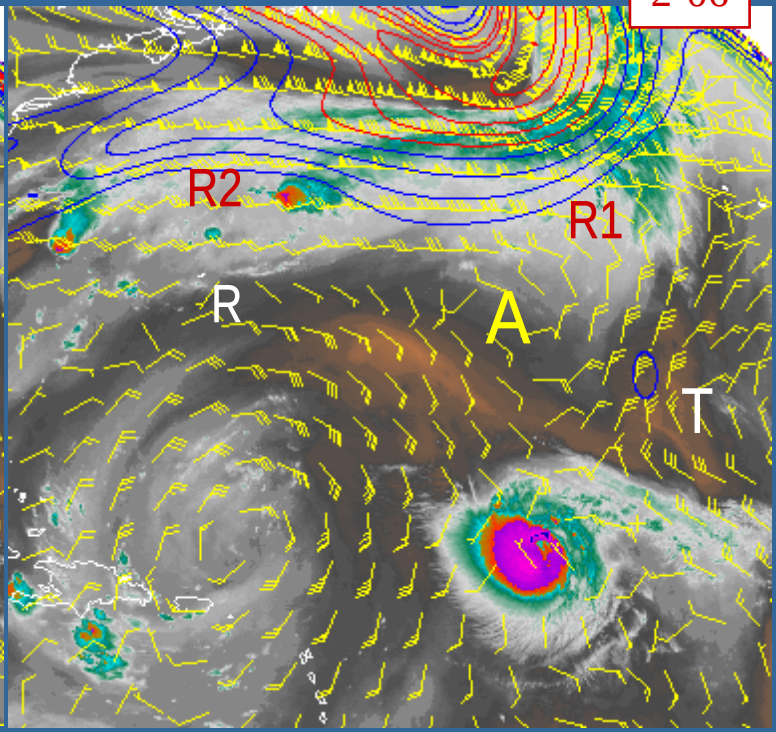
Many “Ridge Roll” events contributed to turns by repositioning or changing the intensities of the local subtropical anticyclones or ridges

Large View 30 hour period TA-03 Isabel 2-06



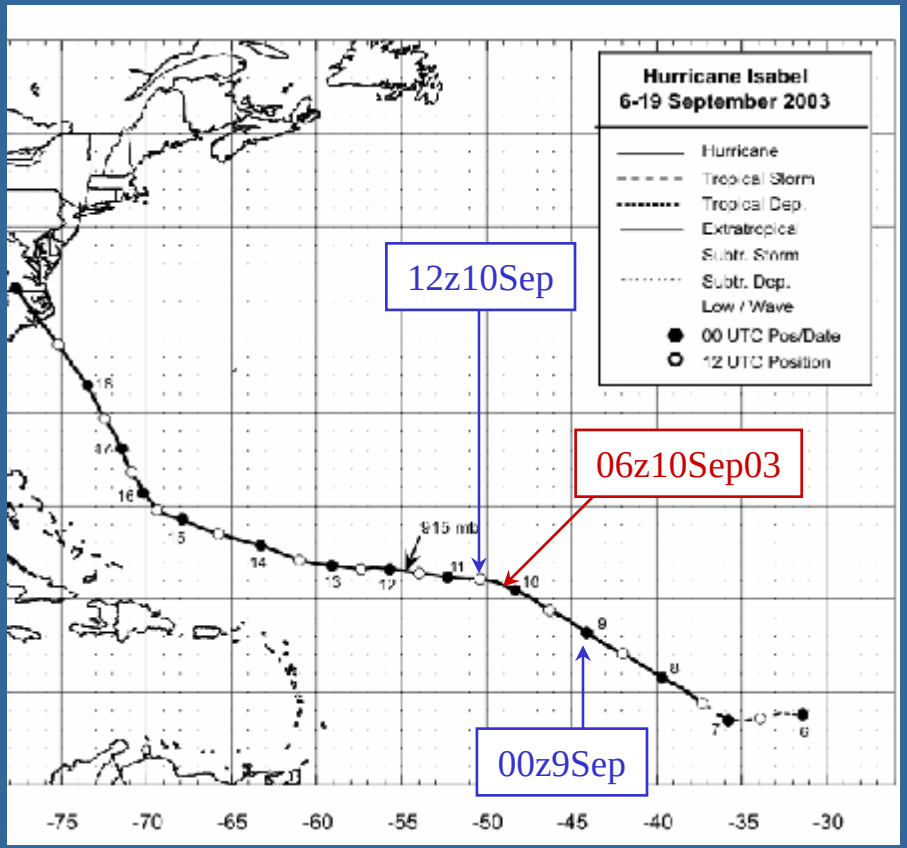




00z 9 Sep 03 300mb GFS Winds 06z 10 Sep 03

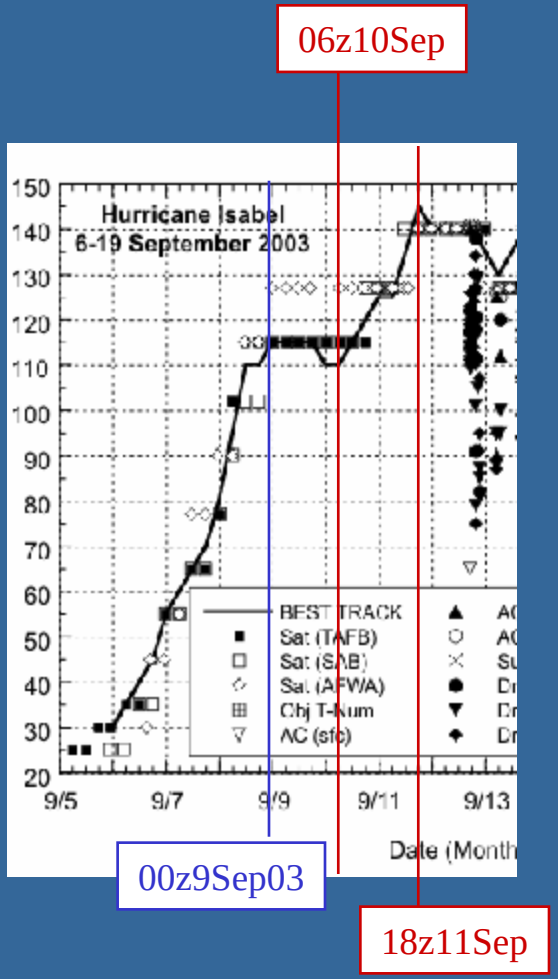
Ridge Roll with Anticyclogenesis Left Turn 305 to 280 degrees
(03z to 12z 10 Sep 03) 115 to 110 knots intensity changes.

(115 to 110 knots 18z 9 Sep to 00z 10 Sep Level to 06z 10 Sep)

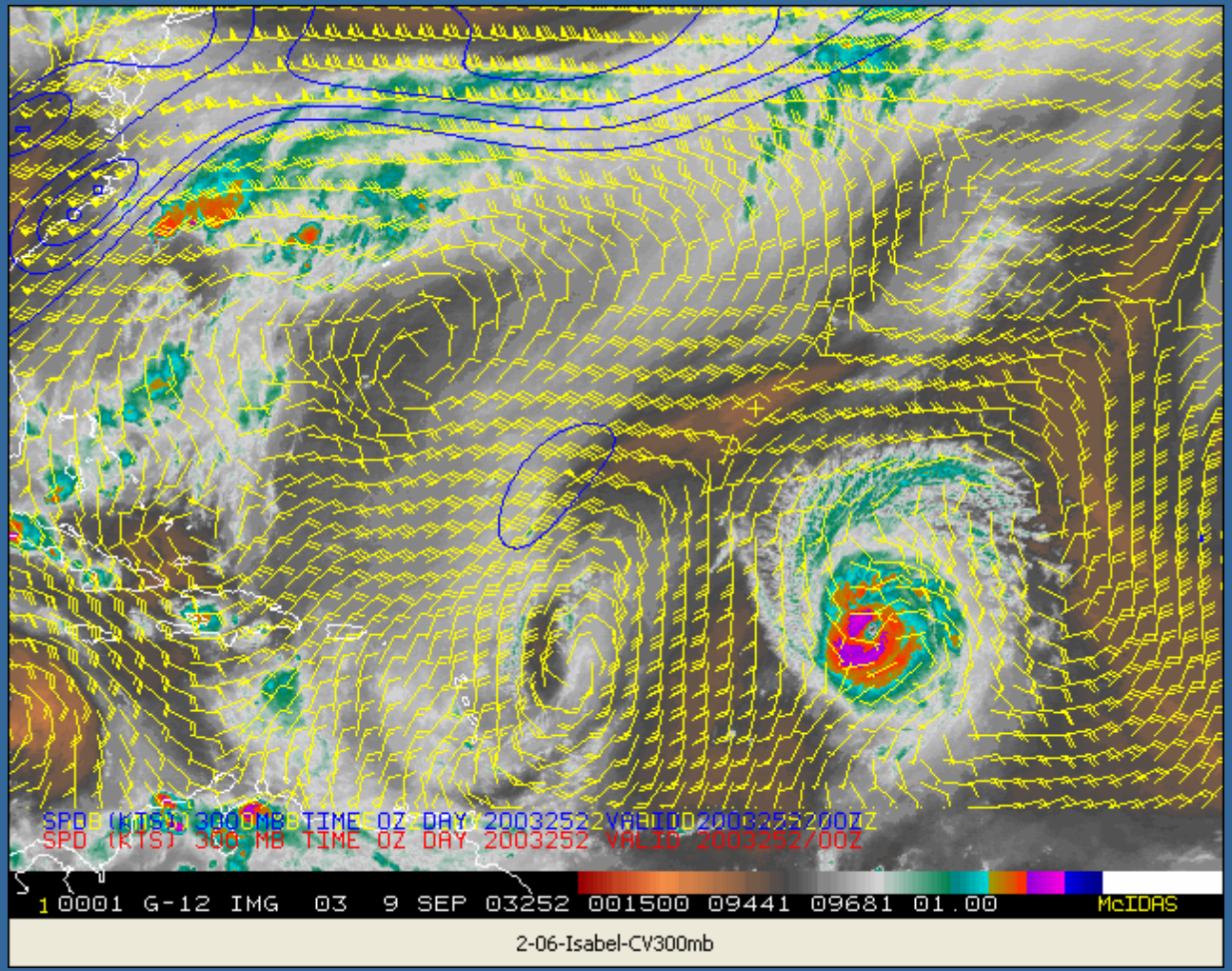
NHC Storm Track TA-03 Isabel



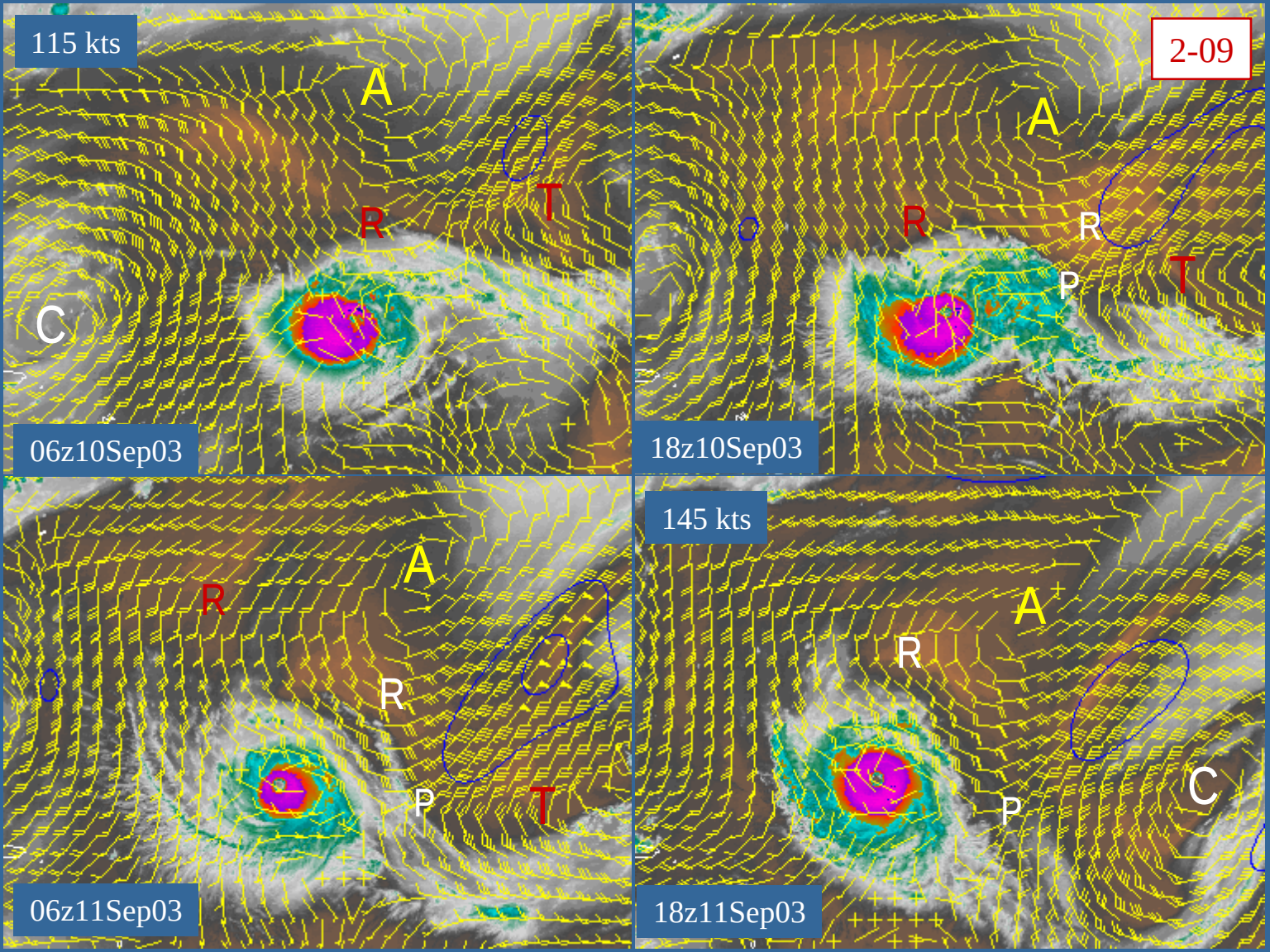

Left Turn 305 to 280 degrees

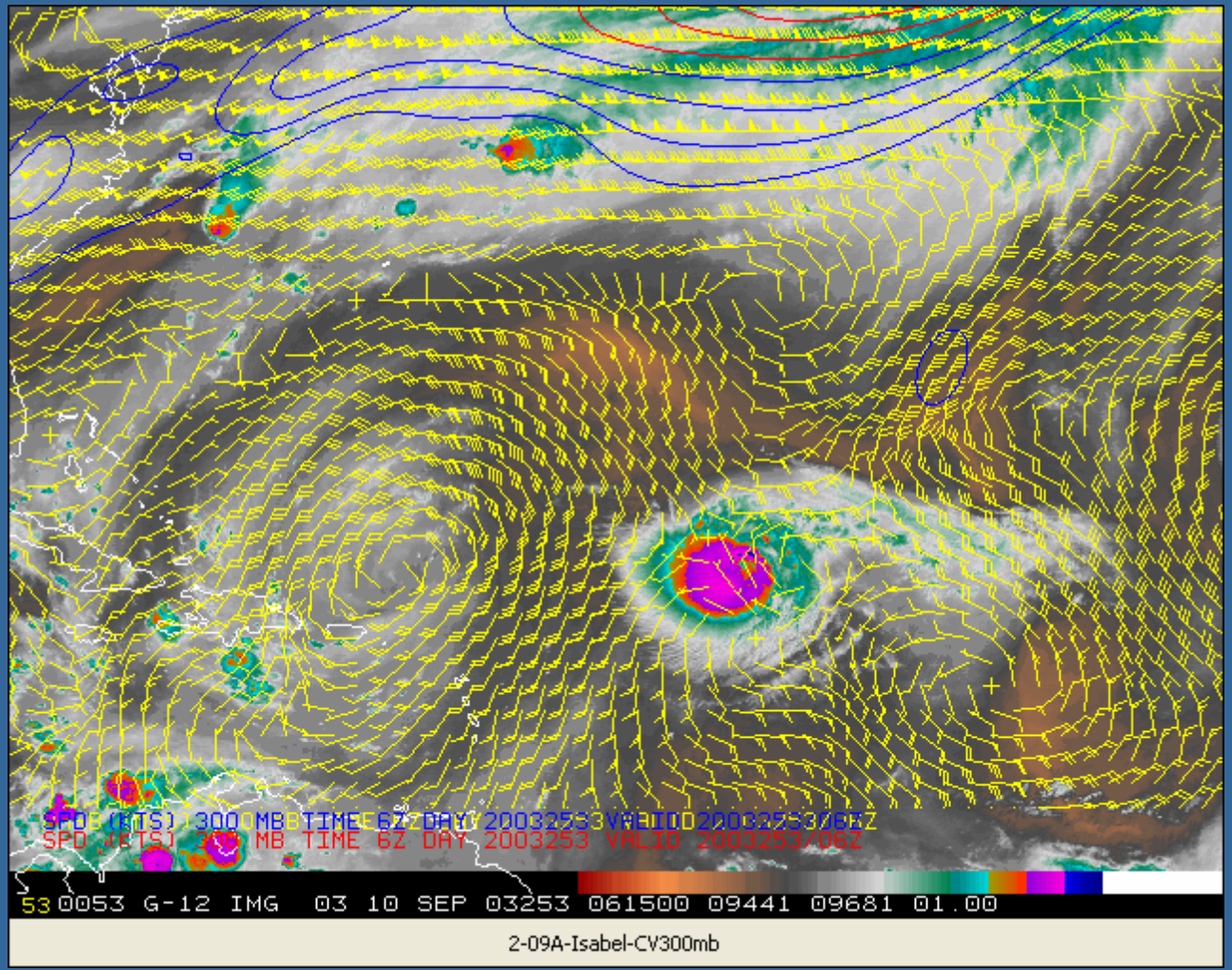



NHC Maximum Wind Speeds




2-06 TA-03 Isabel CV300mb Winds 00z 09 Sep - 06z 10 Sep 03


115 kts
A
R
T
C
06z10Sep03
2-09
A
R
R
P
T
18z10Sep03
R
A
R
P
T
06z11Sep03
145 kts
A
R
P
C
18z11Sep03




2-09A TA-03 Isabel CV300mb Winds 06z 10 Sep - 18z 11 Sep 03

# 120 Ridge Roll Events Identified

In 23 cases the Tropical Cyclones Formed and Intensified

Of the 97 cases in which storms were present at the beginning of the ridge roll event:

77 (79%) Storms intensified significantly from the beginning to end of the ridge roll event.

20 storms did not intensify significantly (10 from the ridge roll itself and 10 for other reasons)

100 storms (83%) either intensified, or formed and intensified, during the 120 ridge roll events.

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Eye Structure Changes:

CDO intrusions observed 19 storms completed an eye replacement cycle

Dry Air Effects:

Dry air was observed entering the storm's cold cloud shield on the 6.7 μm WV imagery

43 cases were coincident in both categories

# Dry Air Effects

# WP-02 Phanfone

Dry Air Ingest CDO Intrusions

with CDO Restructure and Eye Replacement

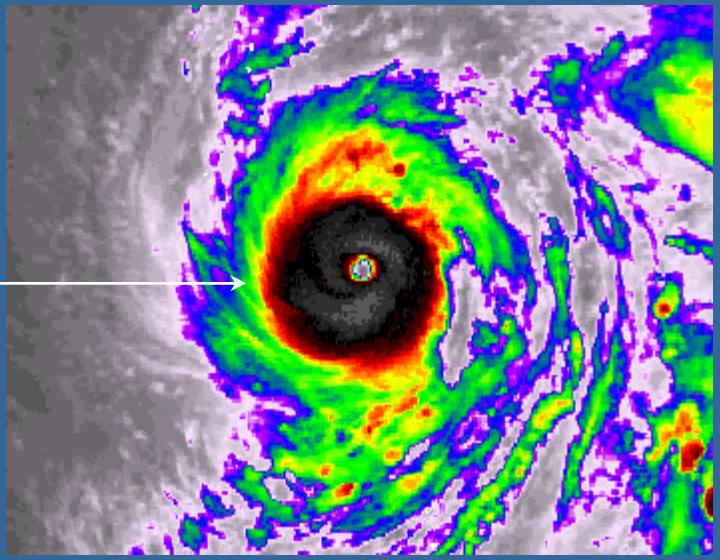
CDO

Central Dense Overcast

Black Region

Min T -81 C

300mb AVN Winds
15z 15 Aug 02

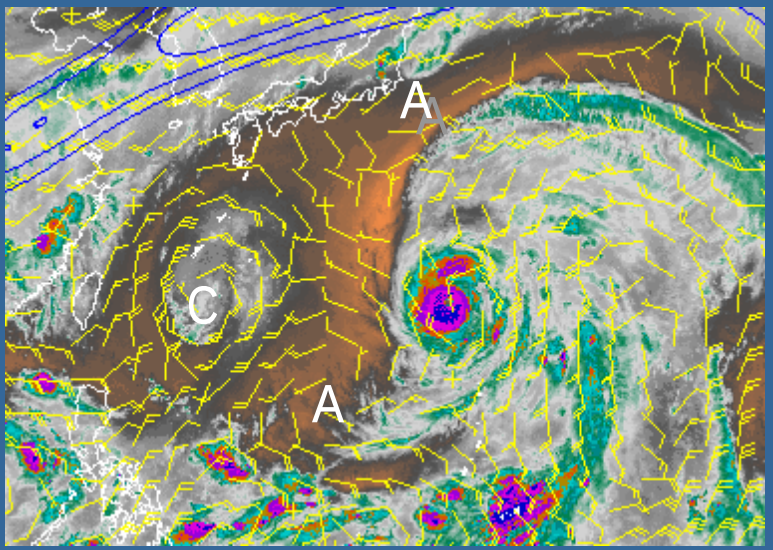


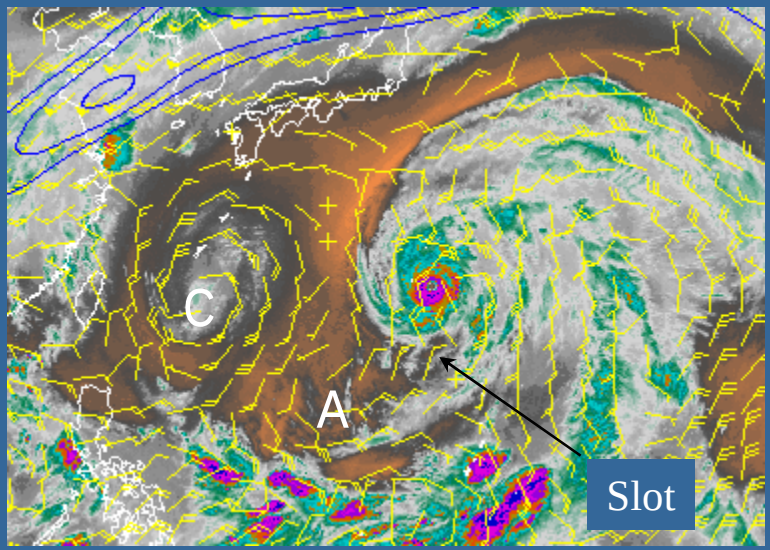
Typhoon Phanfone

130 knots Intensity

IR Image 1232z
15 August 2002

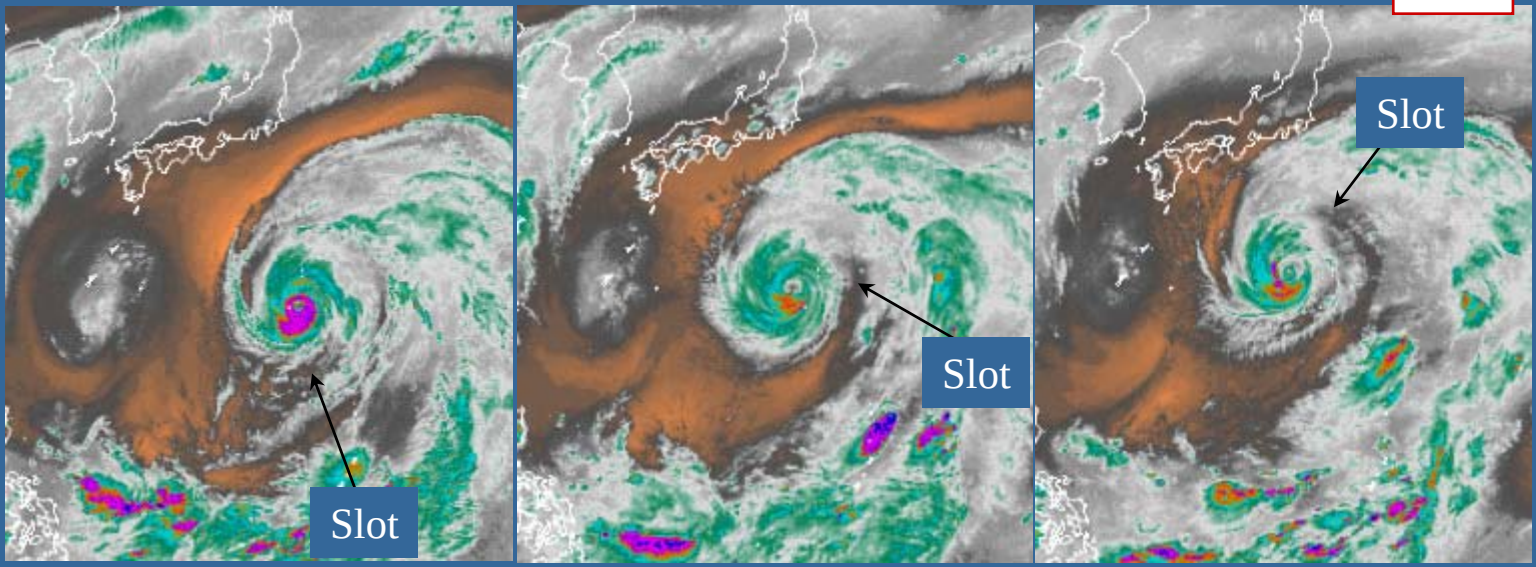
300mb AVN Winds
21z 15 Aug 02



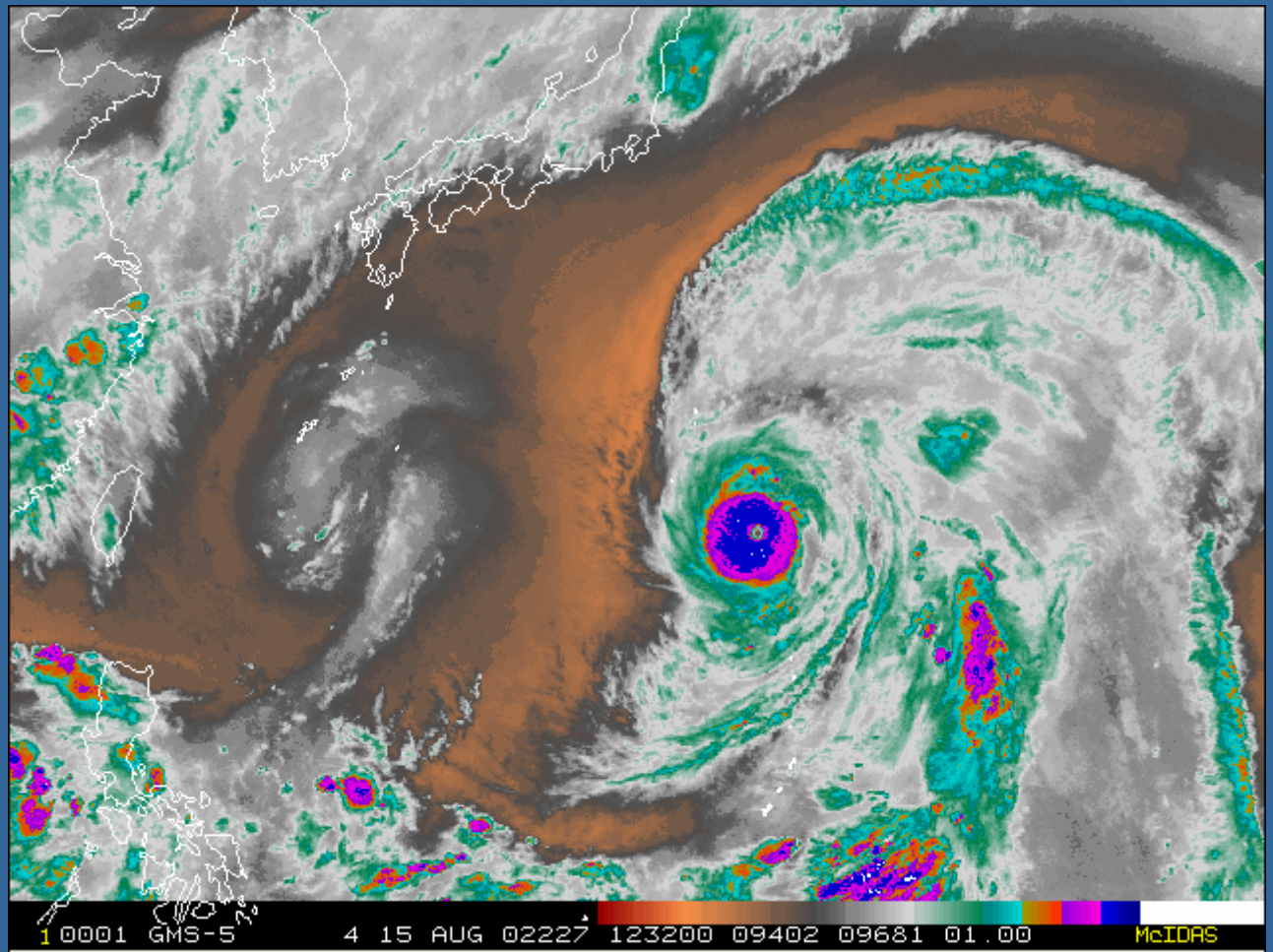
The cold low west of Phanfone slowed its westward movement, dry air formed a slot.

4-02



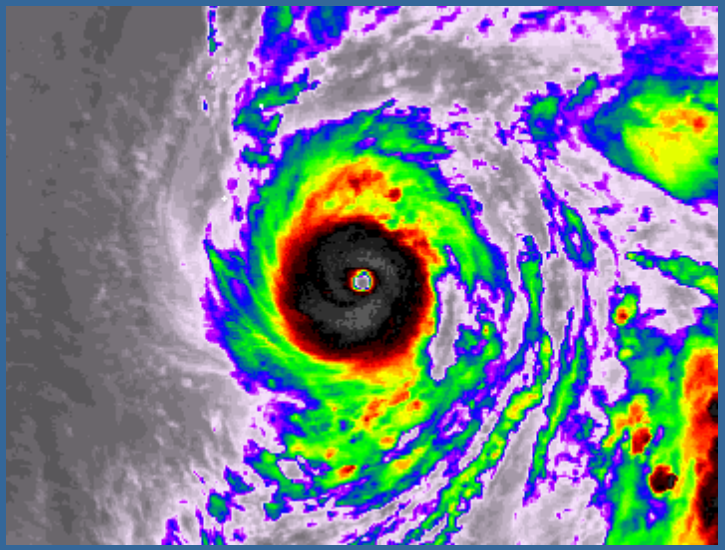

0032z 16 Aug 02 0932z 1832z Water Vapor

The dry slot moved from the south side of the TC to the NE side during the 18 hours

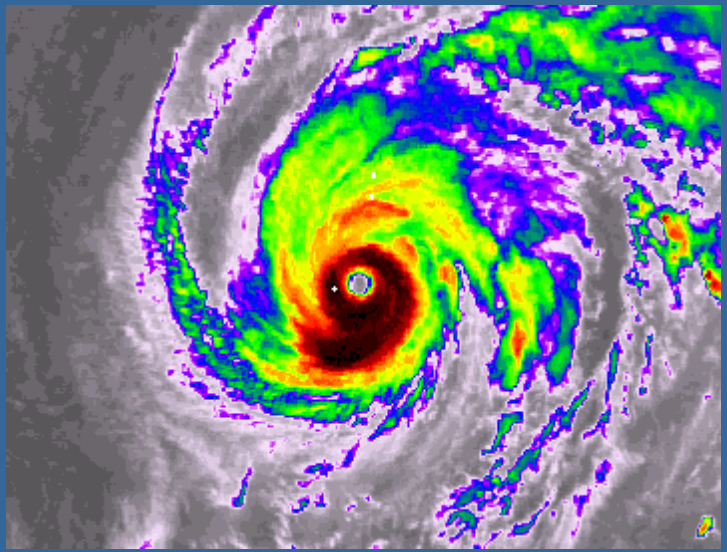



WP02 Phanfone WV Full Period 1232z 15 Aug - 1232zz 17 Aug 02 RES=8

Phanfone IR Images 12 Hour Interval



1232z 15 Sep 02 130 knots



0032z 16 Sep 02 130 knots

The CDO cloud pattern became "intruded" with spiral shaped bands

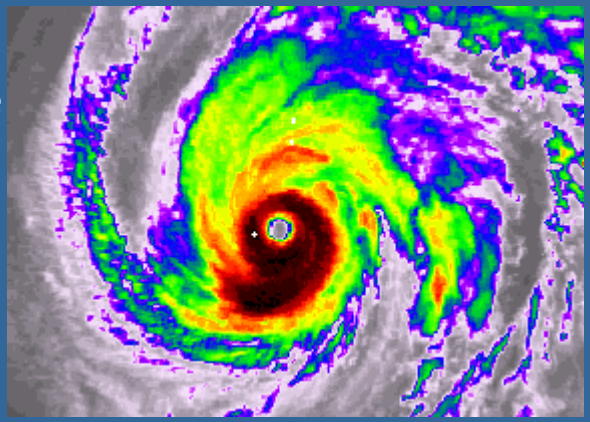
Island is Iwo Jima Black area on the IR image is near -79 degrees C to -81 C in gray part

4-03

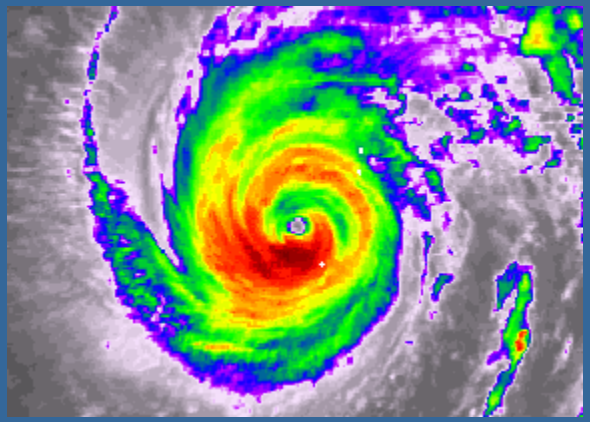
WP-02
Phanfone

0032z
16Aug02

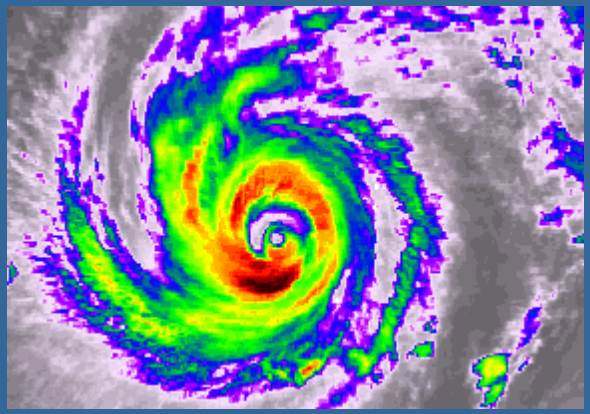
130 kts



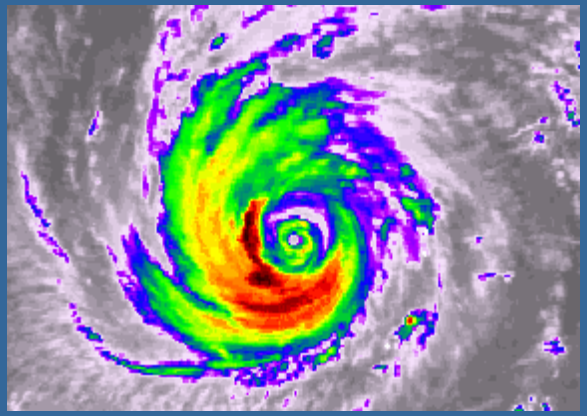
0632z
16Aug02



1232z
16Aug02



1832z
16Aug02



Warm

Cold

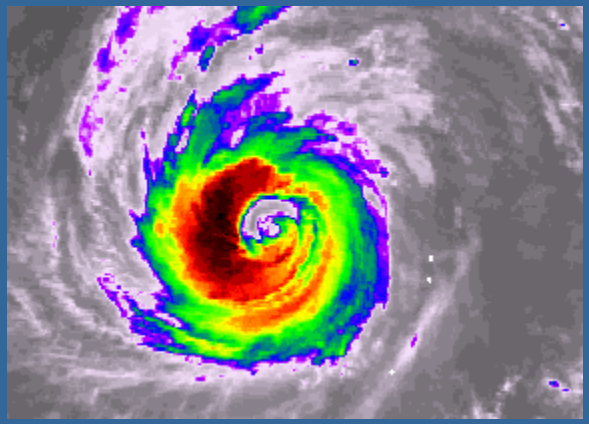
A

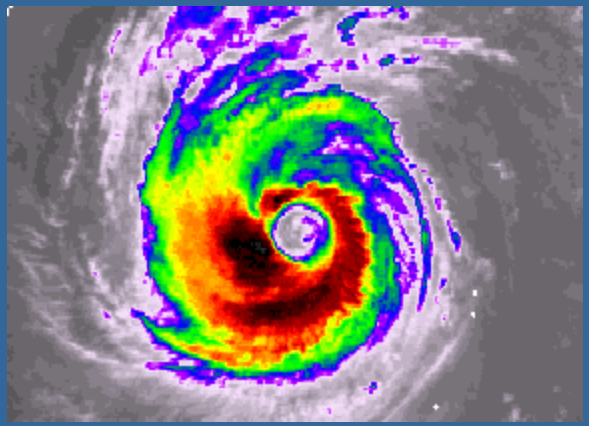
4-04

WP-02
Phanfone

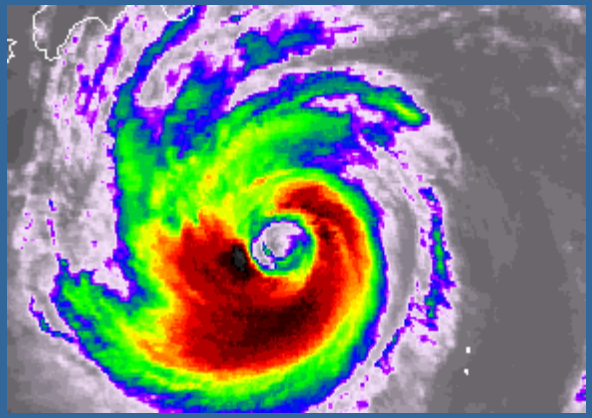
0032z
17Aug02

115 kts

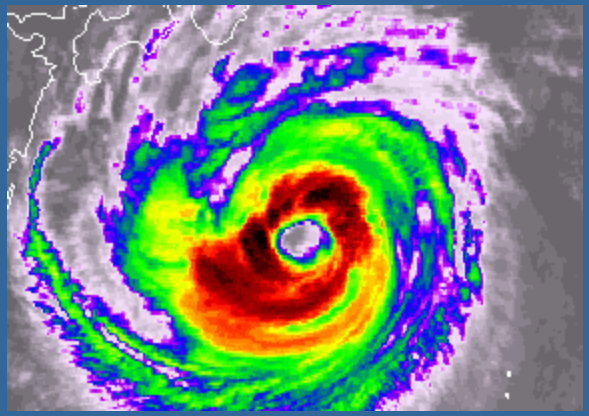




0402z
17Aug02



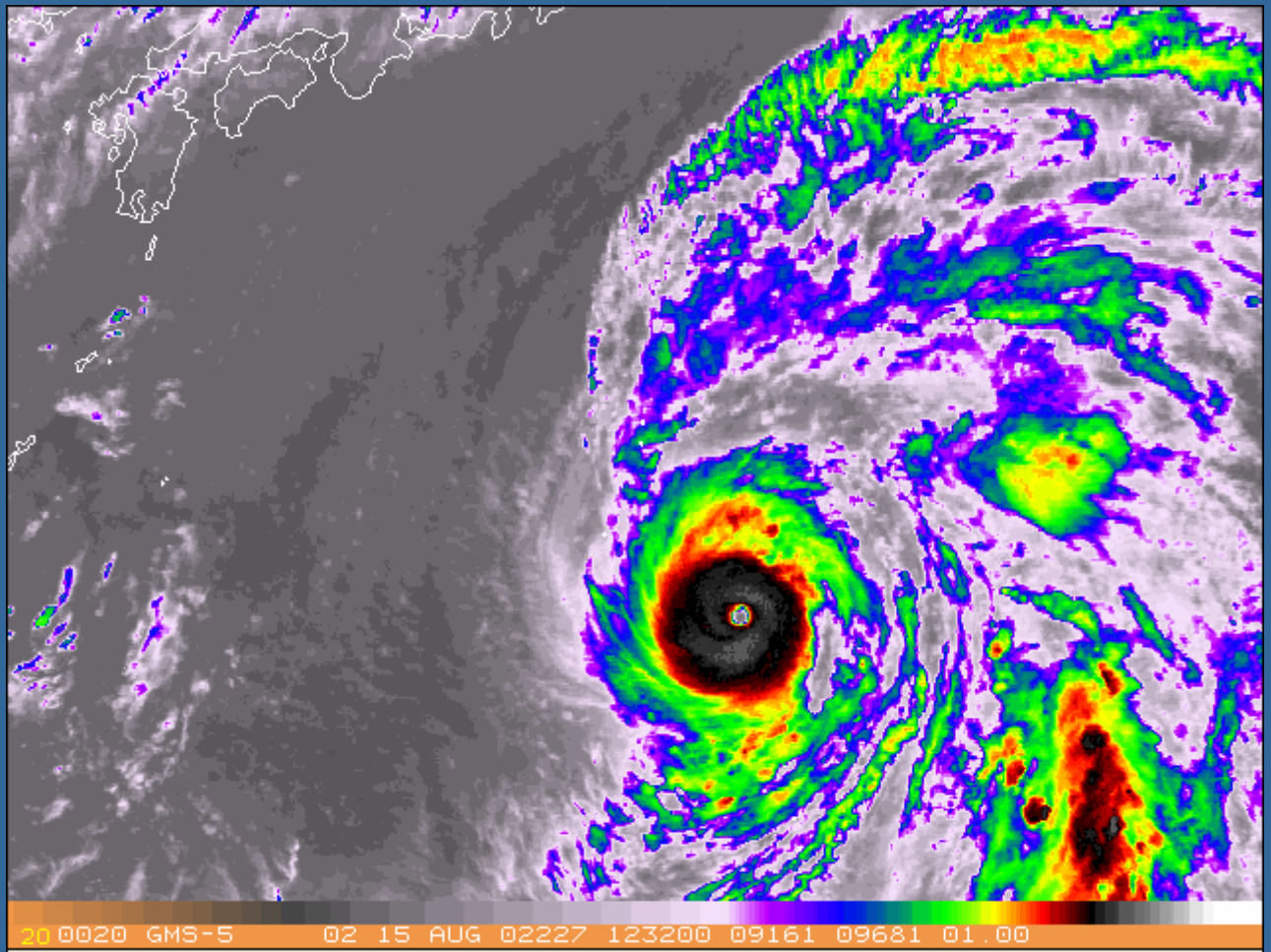
0832z
17Aug02



1232z
17Aug02

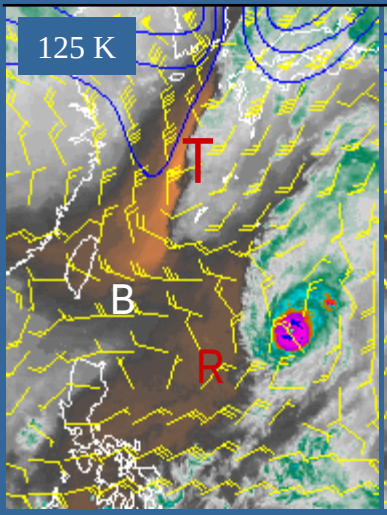
110 kts

B

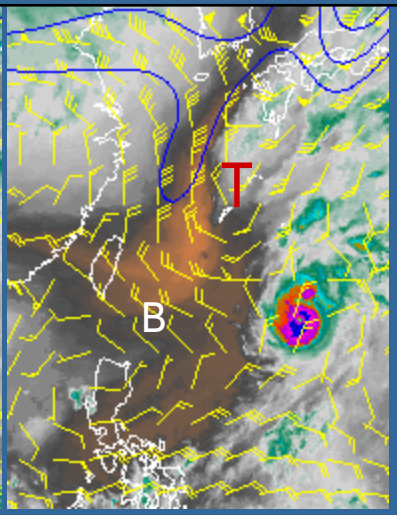



WP02 Phanfone IR Full Period 1232z 15 Aug - 1232zz 17 Aug 02

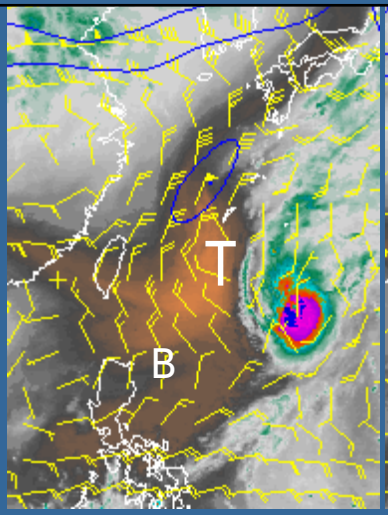
# WP-04 Meari



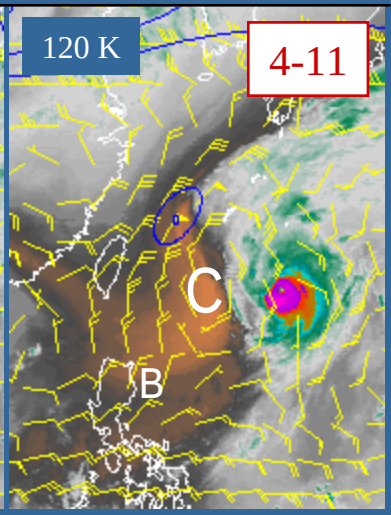

06z 24 Sep 04



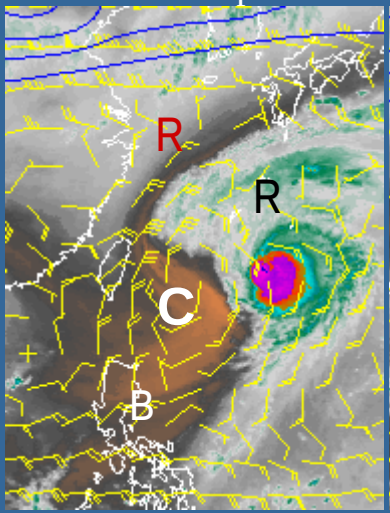

12z 24 Sep 04



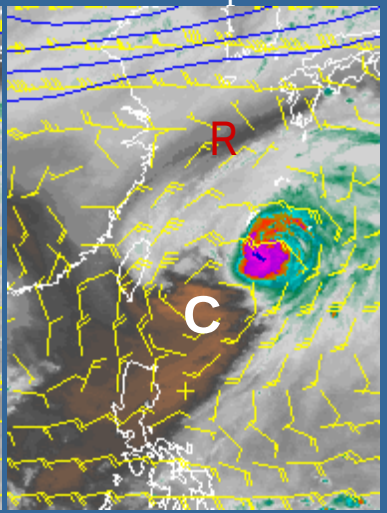

18z 24 Sep 04



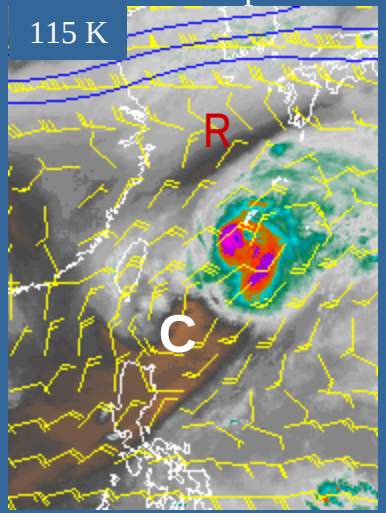

00z 25 Sep 04




06z 25 Sep 04




12z 25 Sep 04



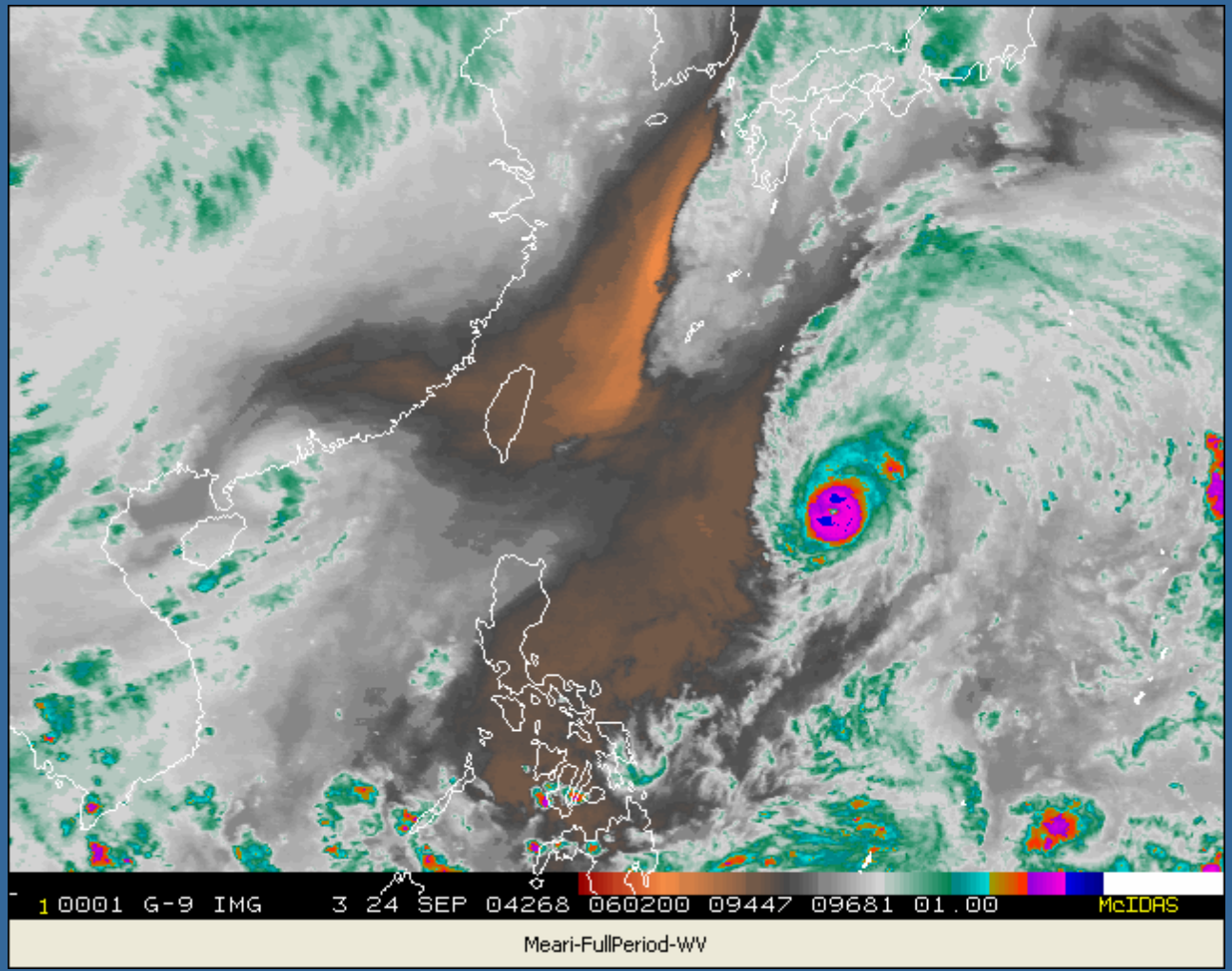

18z 25 Sep 04

WP-04 Meari

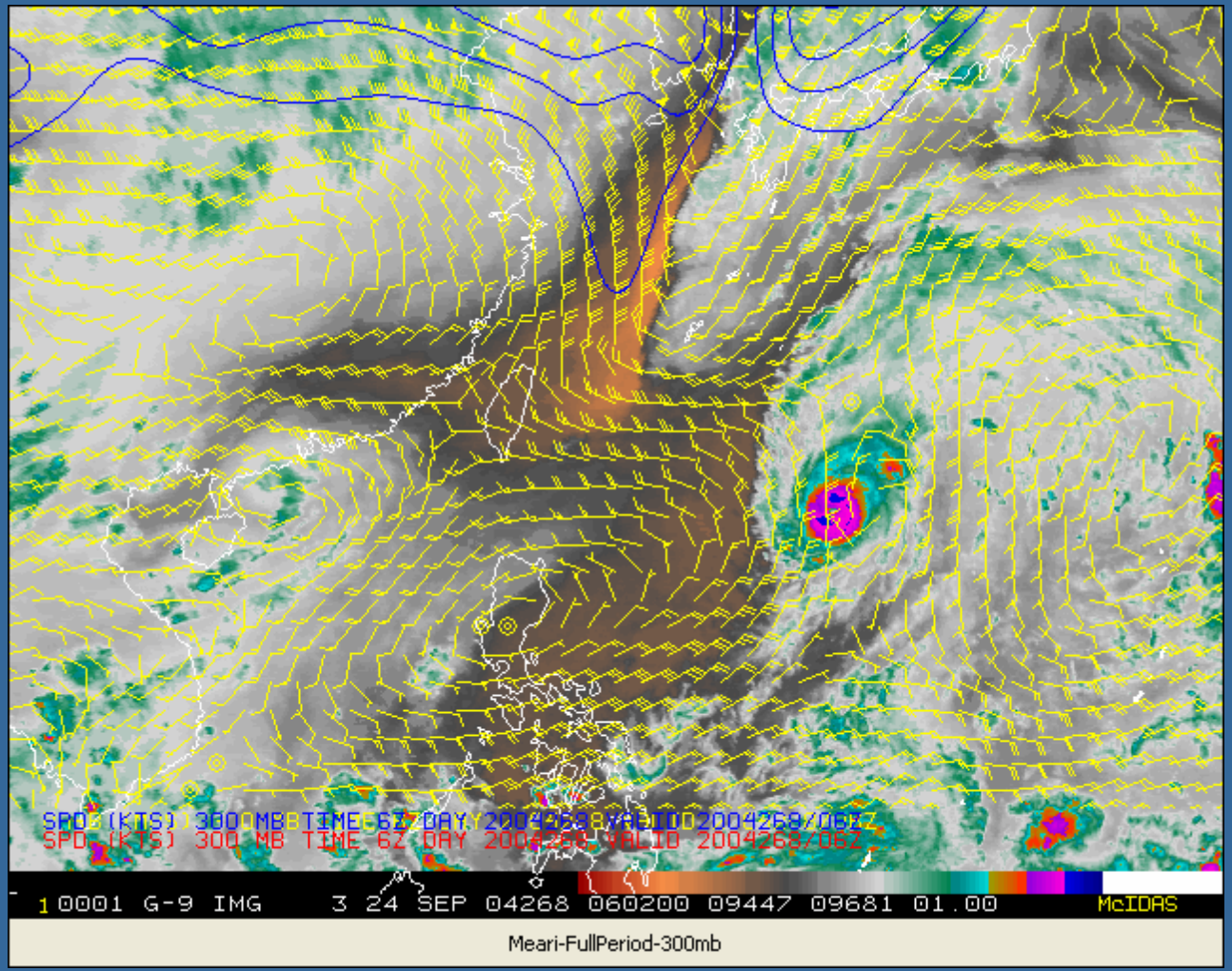
Weakened 125 knots
12z 24 Sep to
110 knots 12z 25 Sep

Ridge Roll “cuts off” cyclone at base of trough

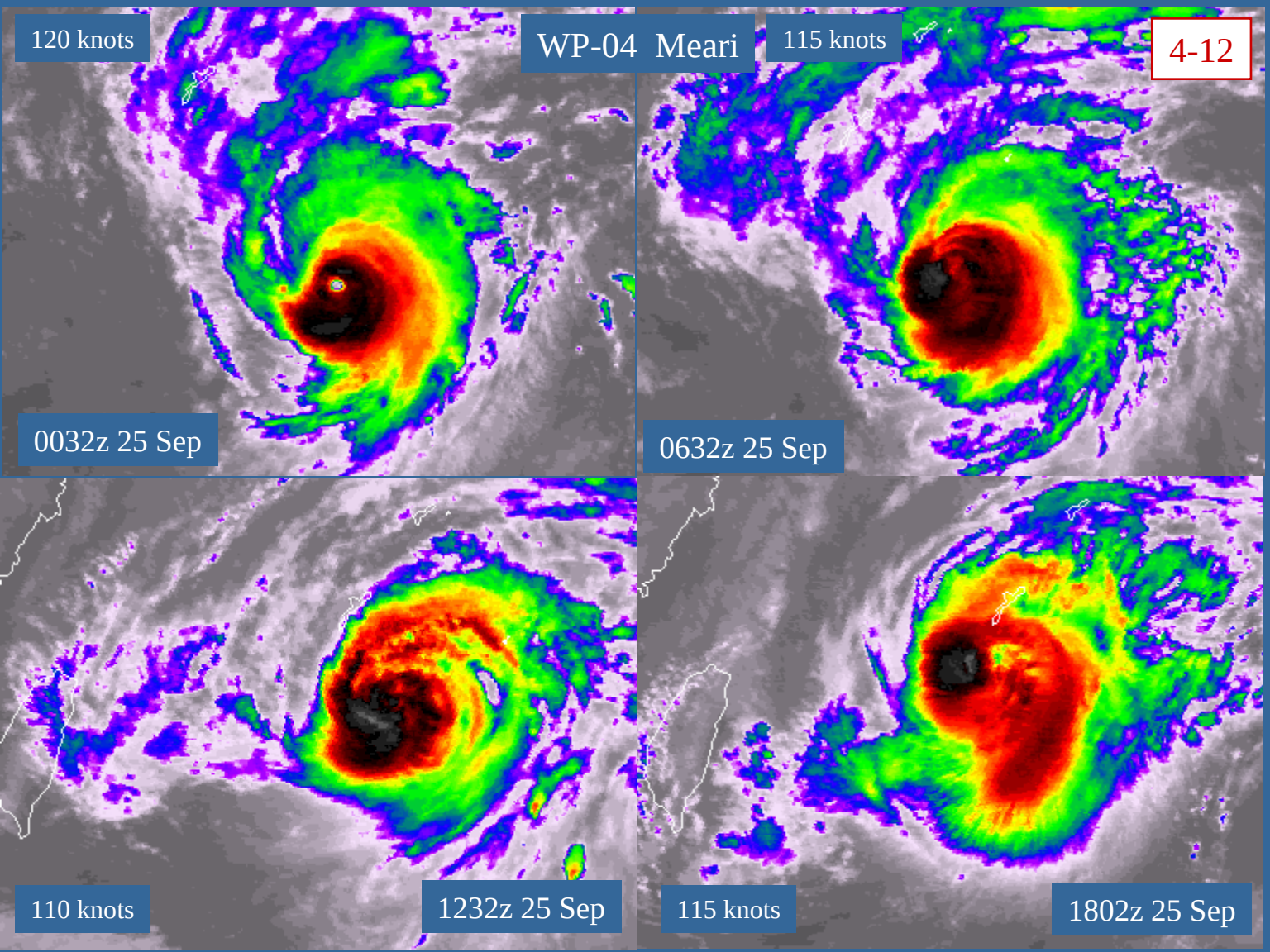
IR Images shown on the next figure

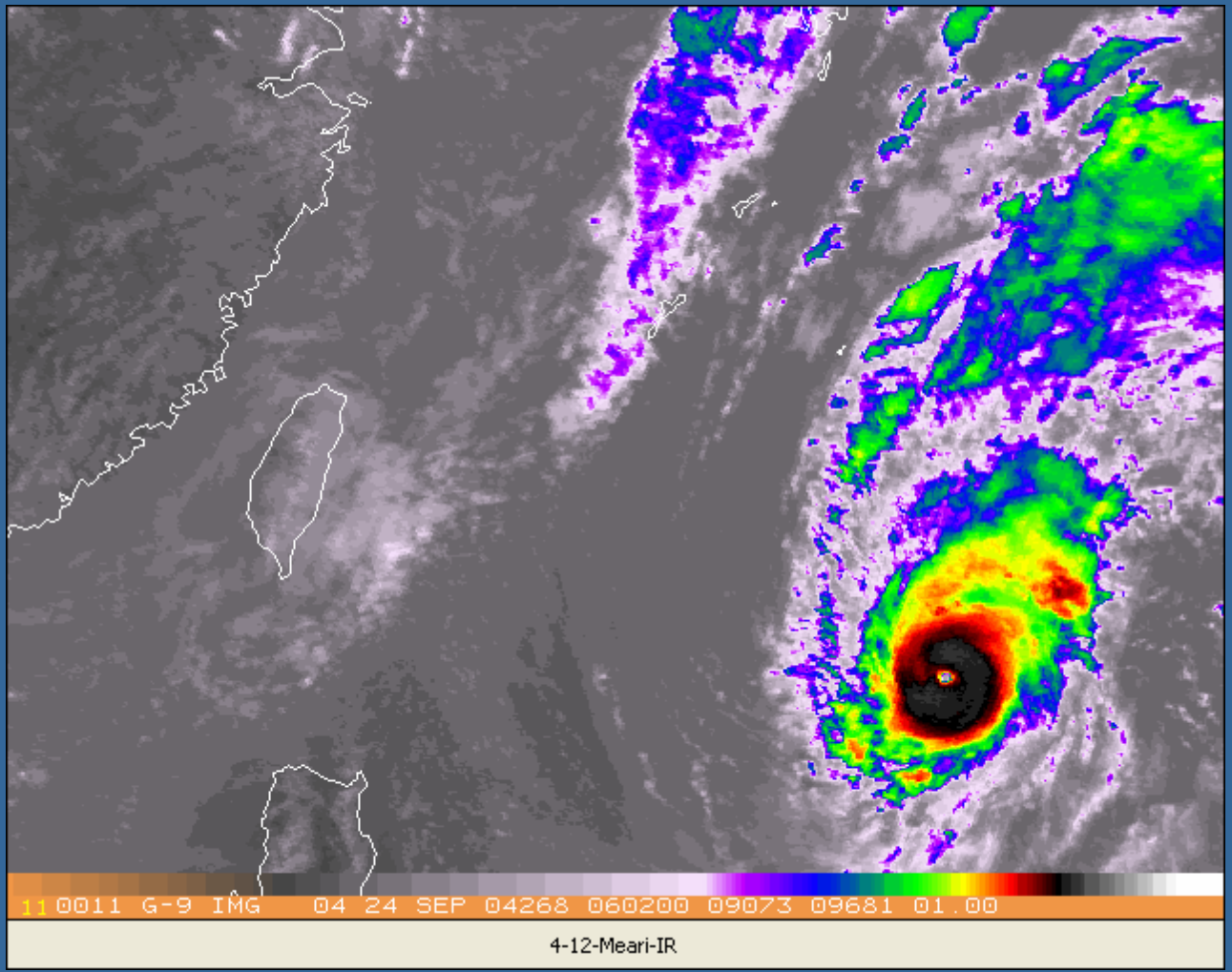



WP04 Meari Water Vapor 06z 24 Sep- 18z 25 Sep 04




WP04 Meari 300mb Winds 06z 24 Sep- 18z 25 Sep 04


120 knots
WP-04 Meari
115 knots
4-12
0032z 25 Sep
0632z 25 Sep
110 knots
1232z 25 Sep
115 knots
1802z 25 Sep




4-12 WP04 Meari IR 06z 24 Sep- 18z 25 Sep 04 (Full 36 hours)

# Two Types of CDO Cloud Top Changes with weakening storms

1. CDO Intrusions
   Alternating spirals of cold and warm clouds, often also accompanied with eye replacement process

   The upper level dry air arrives at the boundary of the Cold Cloud Shield at small angles. The dry air is "ingested"

2. CDO "Deforming"
   The CDO shape is "deformed" to a non circular pattern, often with the eye covered over, or no longer discernible.

   The dry air arrives at the boundary of the Cold Cloud Shield at large angles, with OPEN flow.

The "open" flow need not be dry on the water vapor imagery to contribute to CDO Deforming and weakening

# EVENTS

## Storm Behavior

Right Turns ---------- 153 Events
Left Turns ---------- 79 Events
Eye Structure Changes ----- 47 Events
Intensification Going East - 21 Events
Demise ---------- 33 Events
Early Storm Structure -------19 Events
Lift Out ---------- 9 Events

Storm Behavior Events 361

## Environmental Changes

Ridge Rolls ---------- 120 Events
Base Surges ---------- 73 Events
Dry Air Effects ---------- 50 Events
**Adjacent System Changes - 76 Events**
DZ Formation ---------- 34 Events
Inside Boundaries ----------23 Events

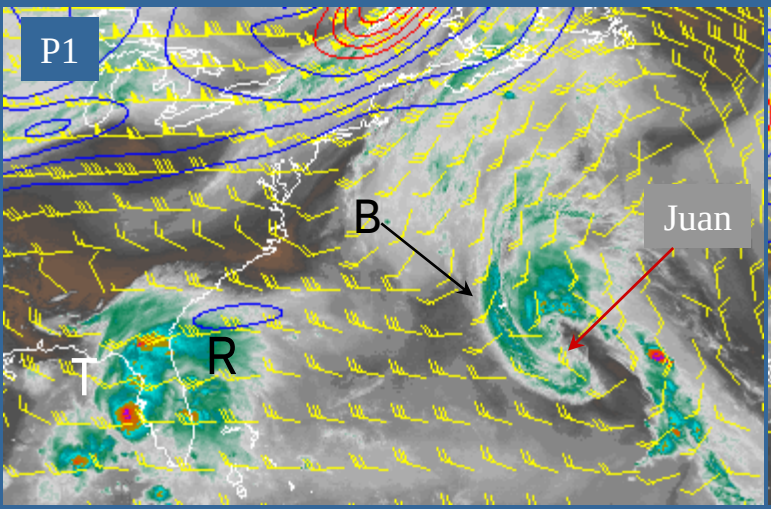
Environmental Change Events 376

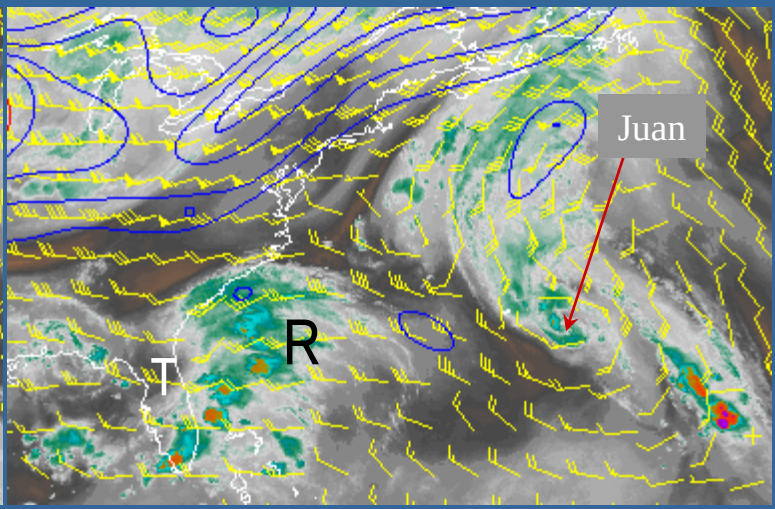
Total Events: 737

Jet Stream Structure Changes, Cold Low Interactions, General Opening or Closing Systems of various categories

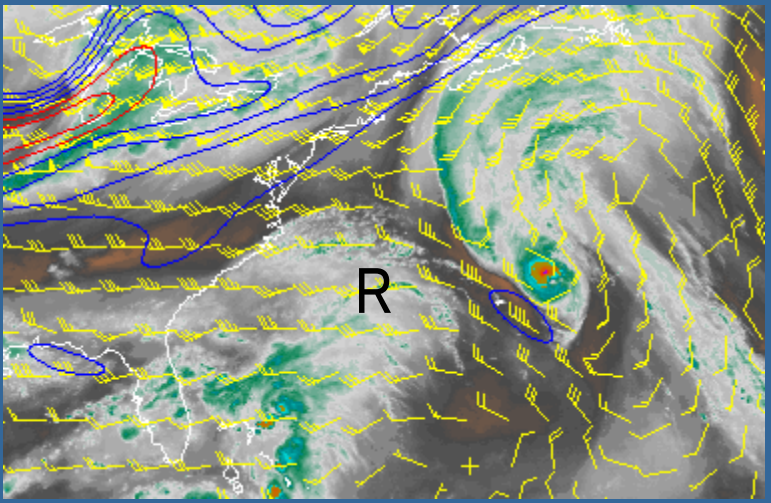
# TA-03 Juan

# Closing -Opening Systems




TA-03 Juan 00z 26 Sep 03 300mb GFS Winds 12z 26 Sep 03




00z 27 Sep 03 300mb GFS Winds

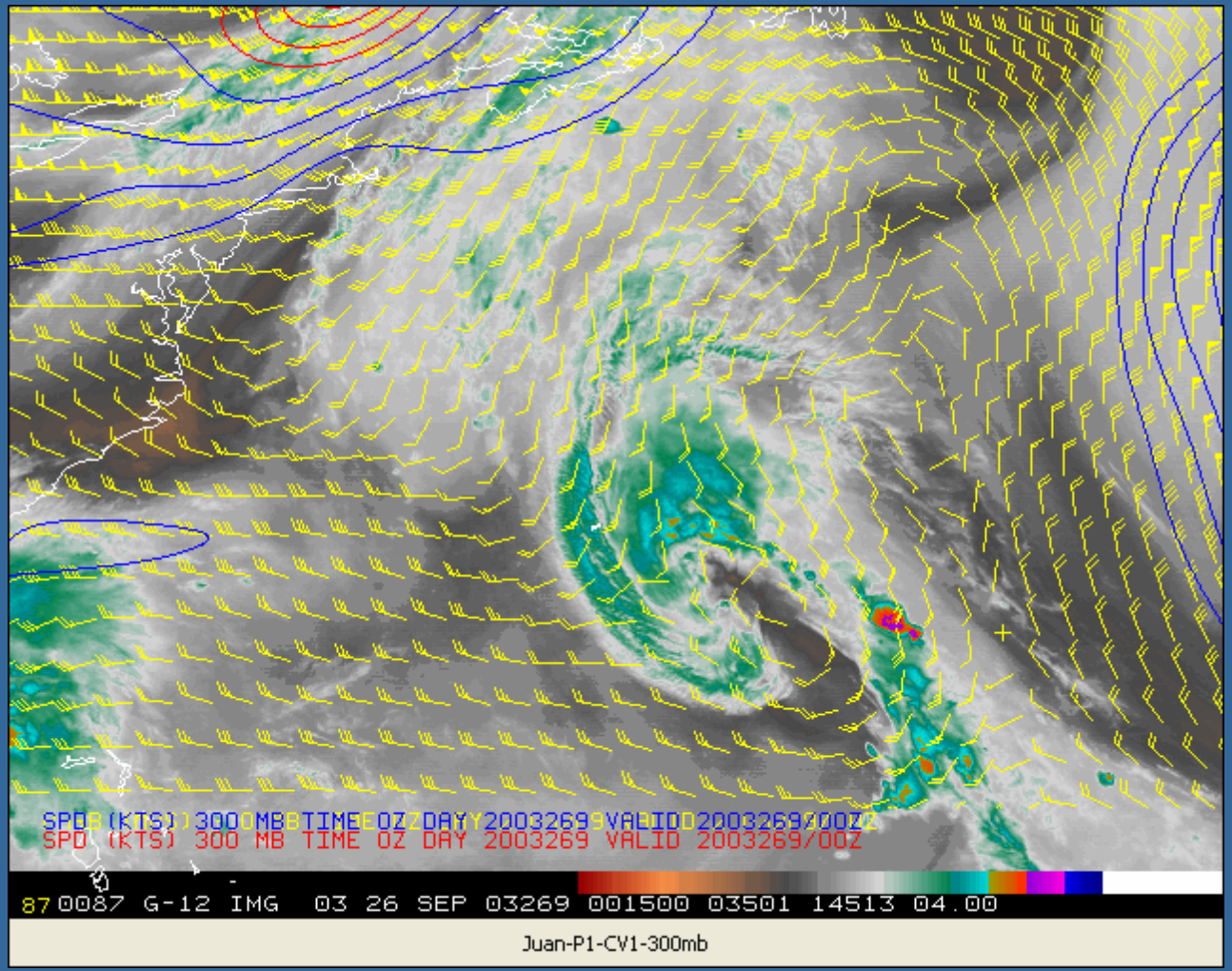
TA-03 Juan Large View

24 Hour Period 1

Intensifies 55 to 65 to 75 knots

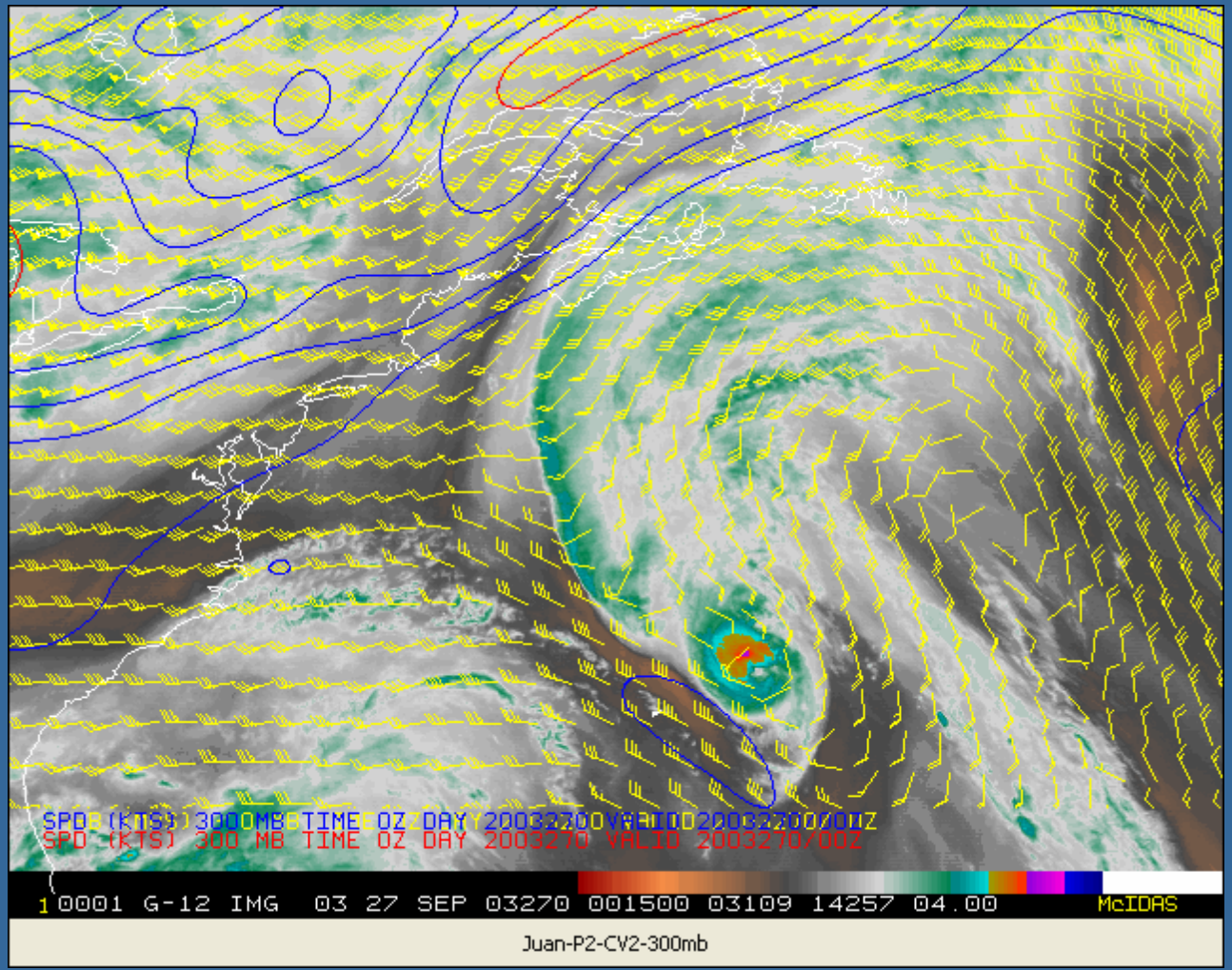
Moving 350 12 hours then 360 second 12 hours

P1



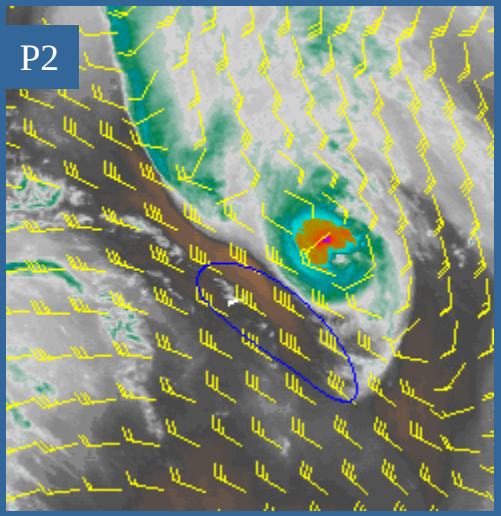

TA-03 Juan CV 300mb Winds 00z 26 Sep - 00z 27 Sep 03

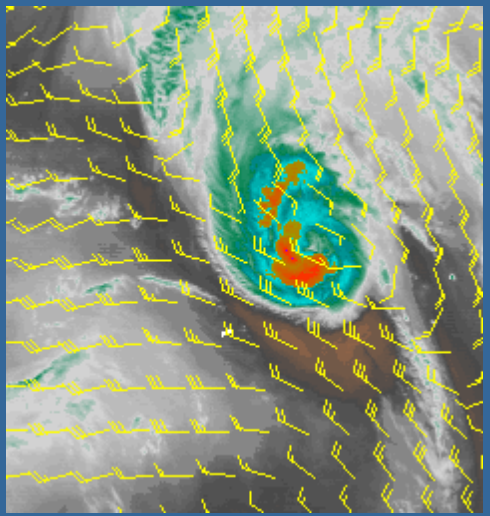
P2

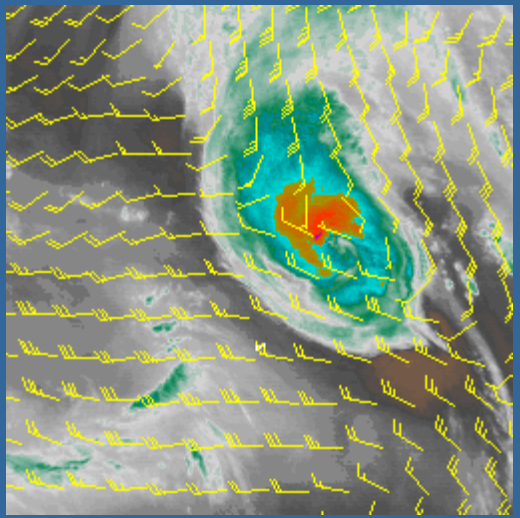



TA-03 Juan CV2 300mb Winds 00z 27 Sep - 09z 27 Sep 03

P2





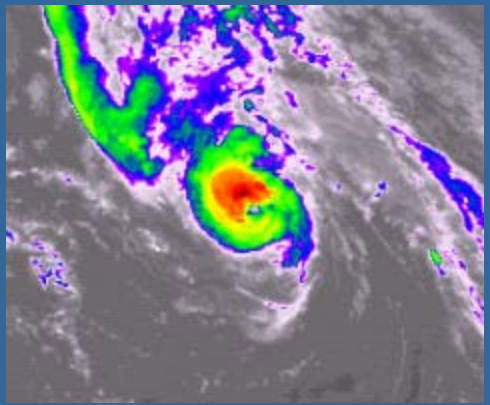


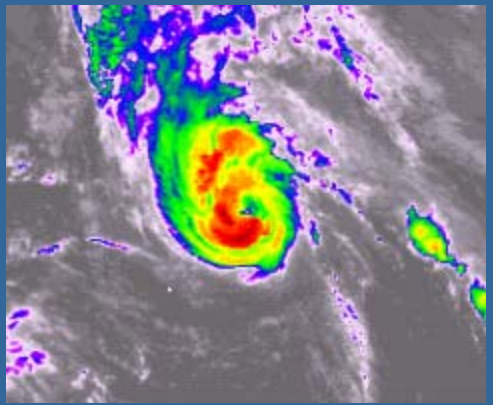
00z 27 Sep 03 300mb

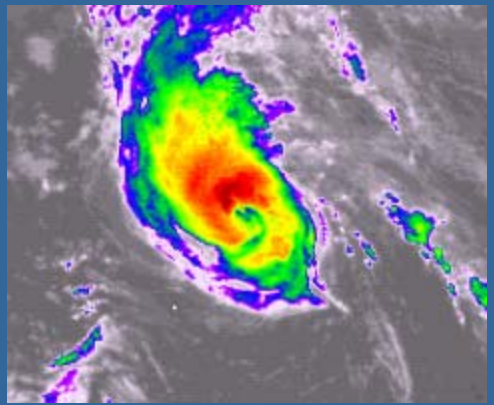
06z 27 Sep 03 300mb

09z 27 Sep 03 300mb

Winds back with time and begin to cross the boundaries at large angles





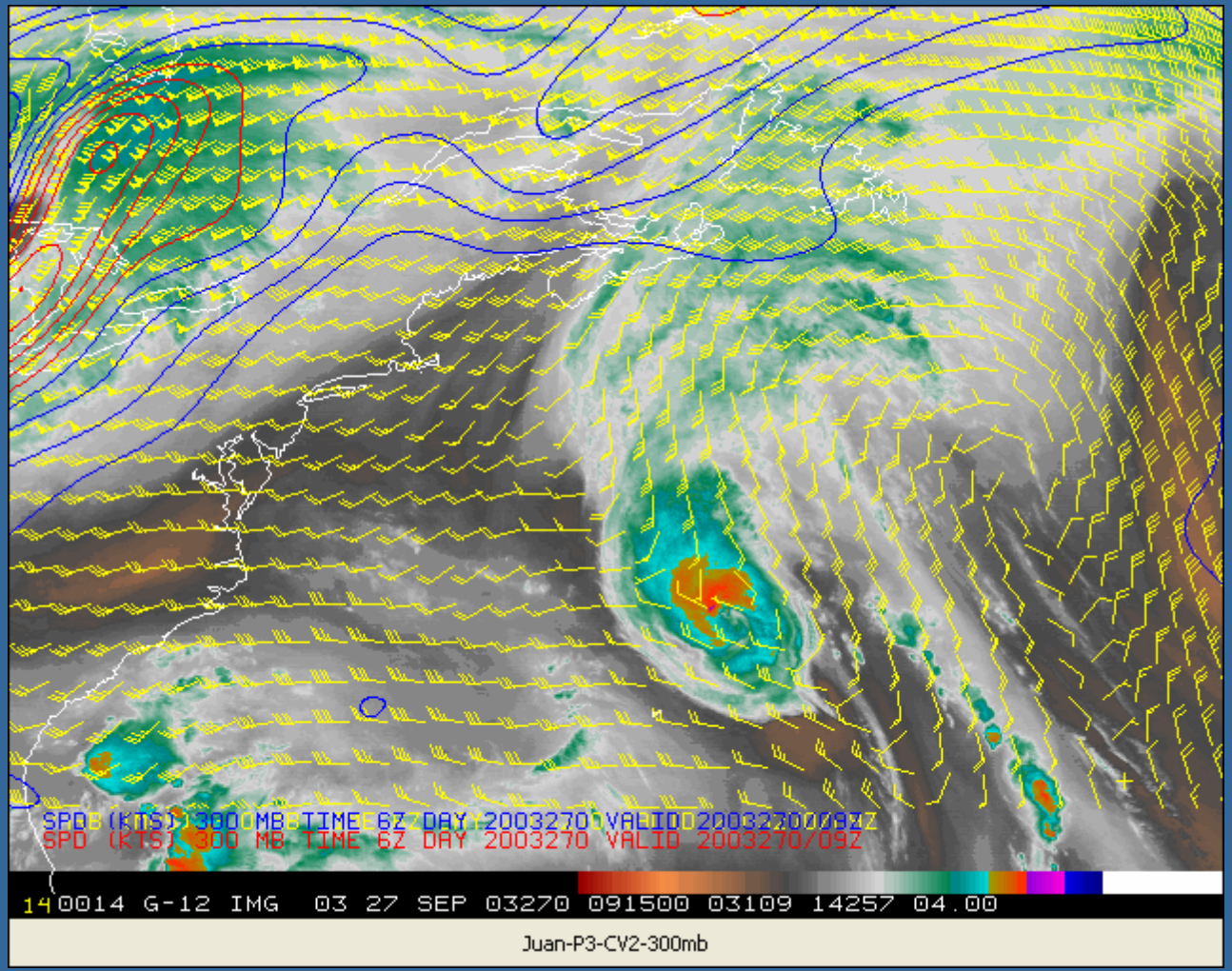


0015z 27 Sep 03

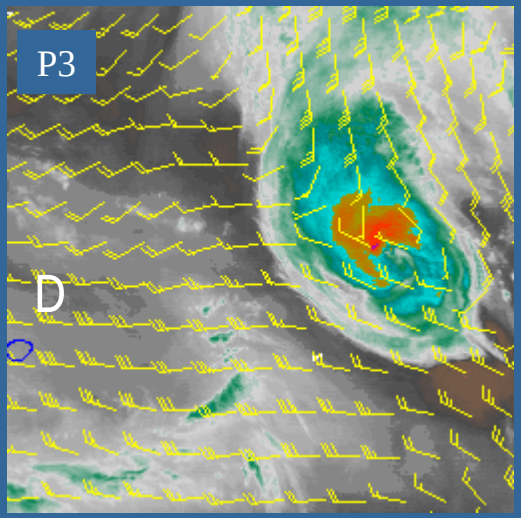
0615z 27 Sep 03

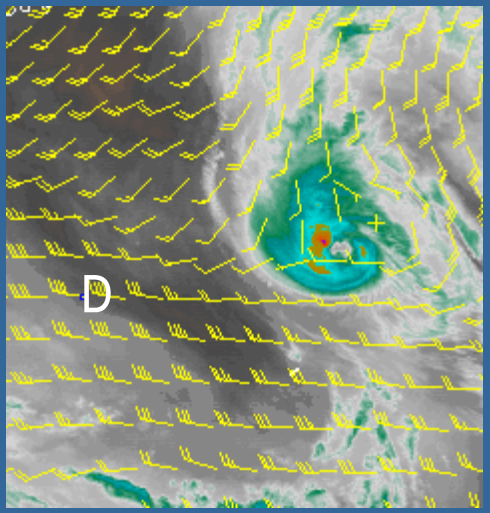
0915z 27 Sep 03

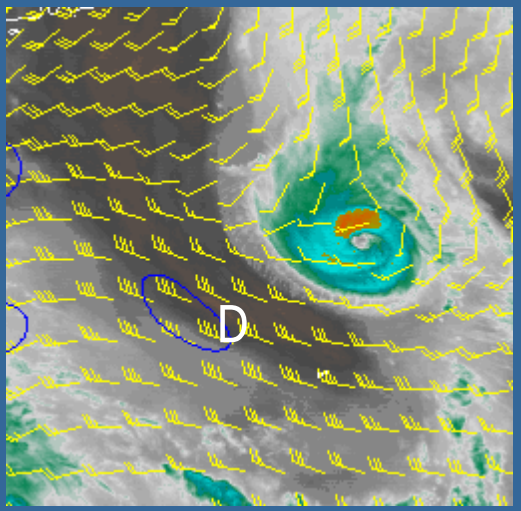
P3




TA-03 Juan CV 300mb Winds 09z 27 Sep - 00z 28 Sep 03



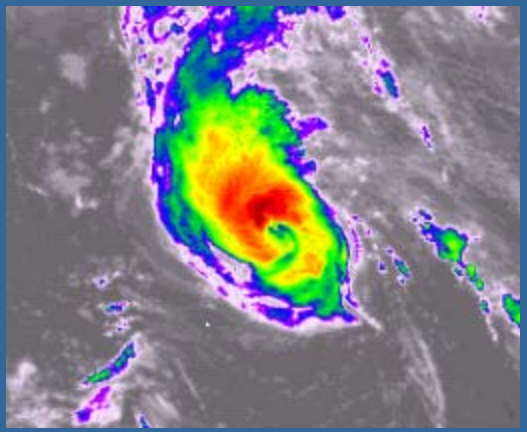



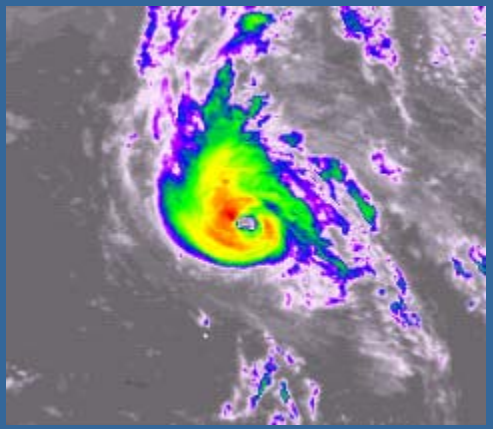

09z 27 Sep 03 300mb

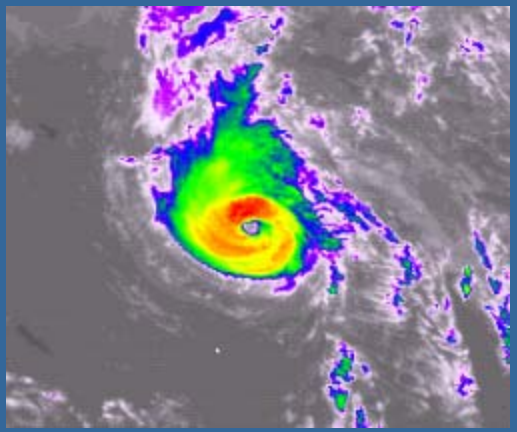
15z 27 Sep 03 300mb

18z 27 Sep 03 300mb

Winds veer with time as an upstream ridge amplifies Become more parallel to boundaries



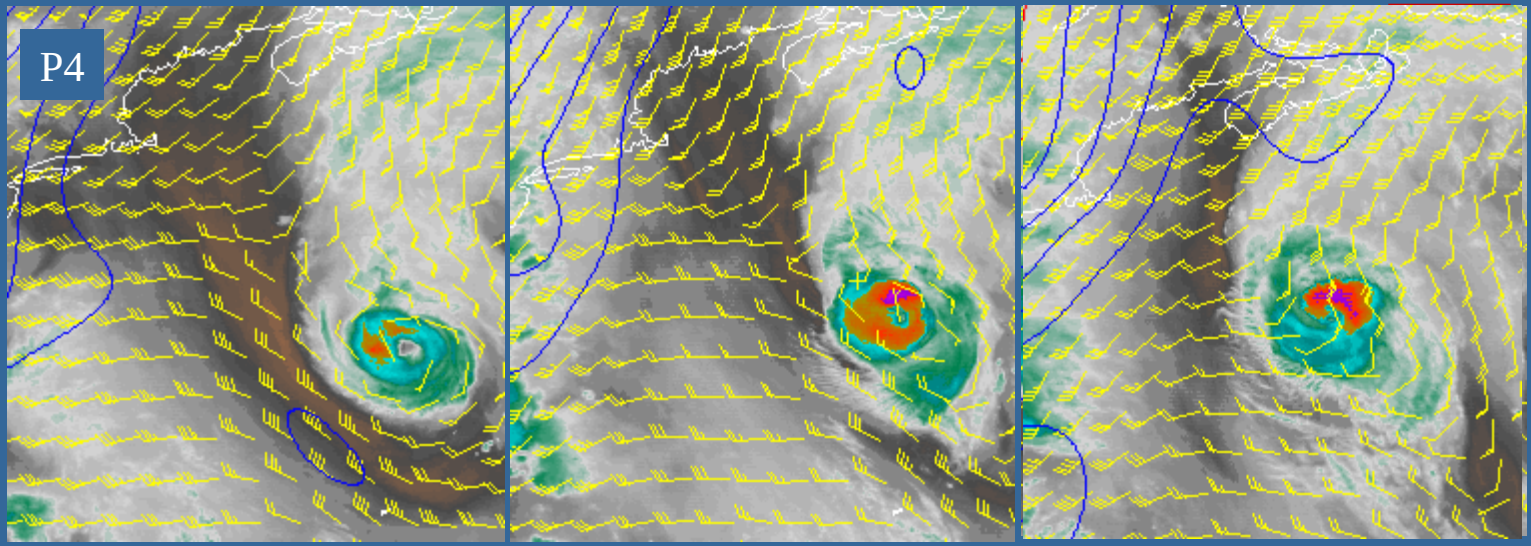


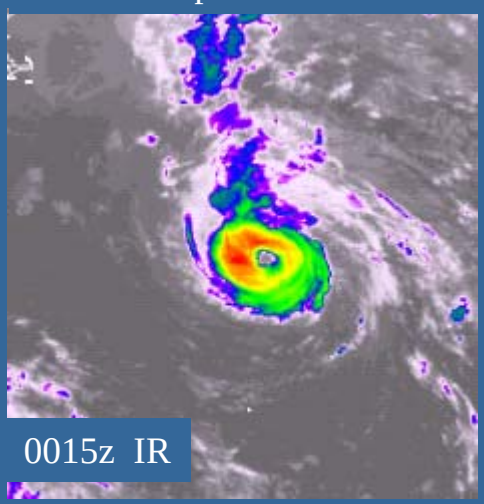


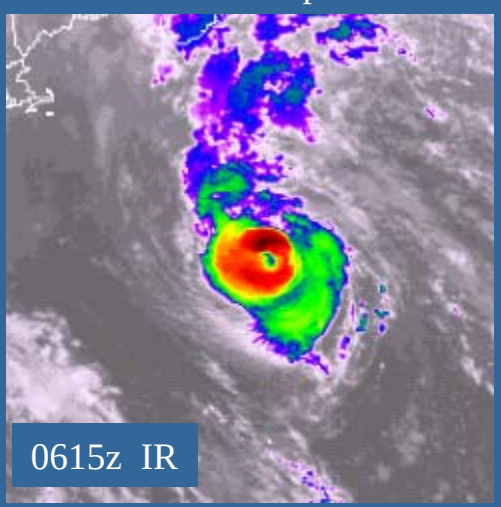
0915z 27 Sep 03 IR

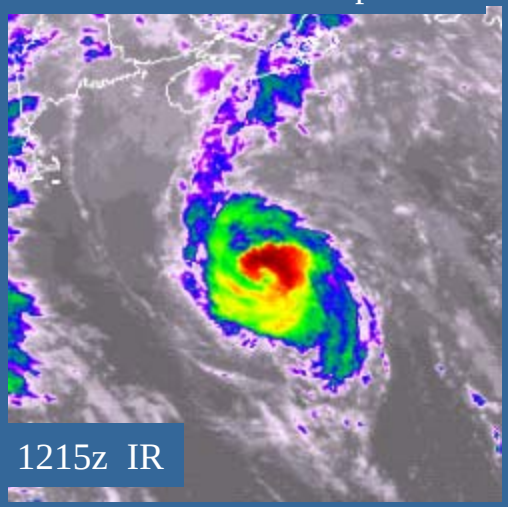
1515z 27 Sep 03 IR

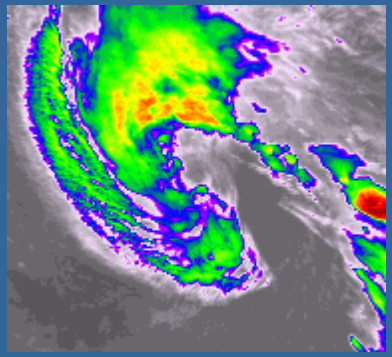
1815z 27 Sep 03 IR


P4
00z 28 Sep 03
300mb GFS Winds
06z 28 Sep 03
12z 28 Sep 03

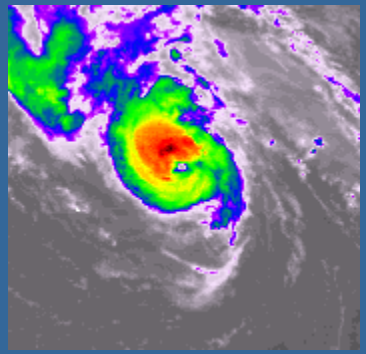

0015z IR


0615z IR

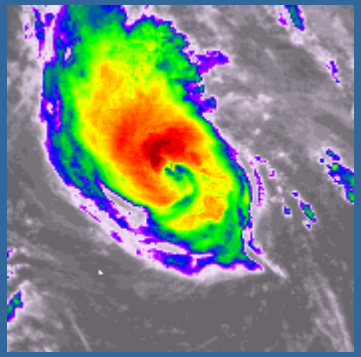

1215z IR



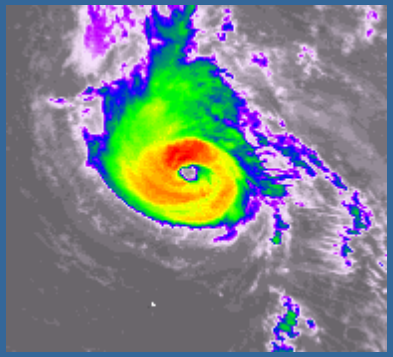
0015z 26 Sep 03



00z 27 Sep 03



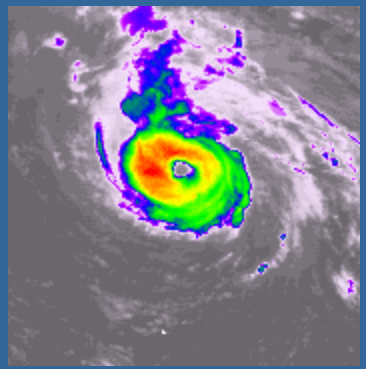
0915z 27 Sep 03



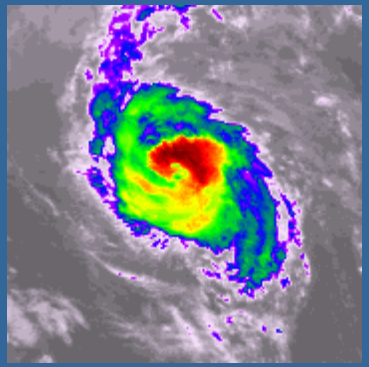
1815z 27 Sep 03

CLOSING → OPENING → CLOSING →

Conditions Holding 1815z 27th to 0015z 28th



0015z 28 Sep 03



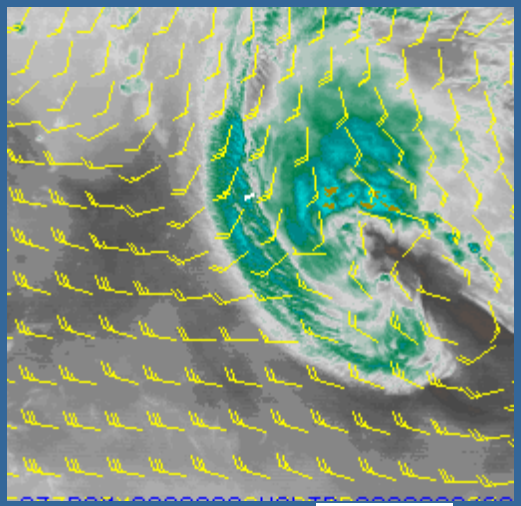
1215z 28 Sep 03

OPENING →

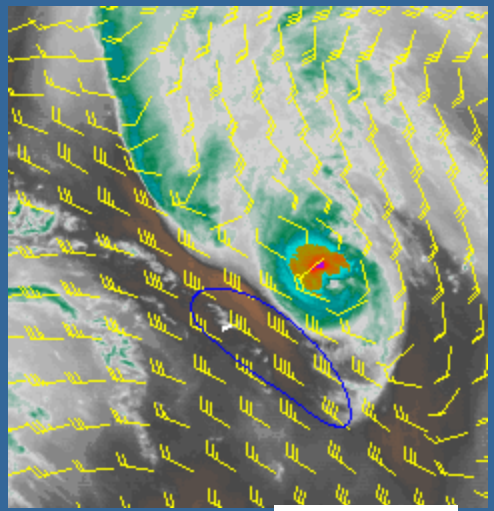
GSF 300mb Winds

Hurricane Juan

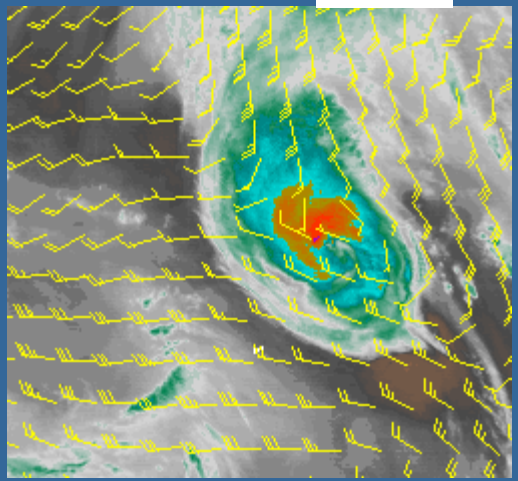
The 09z data are a
3 hour forecast



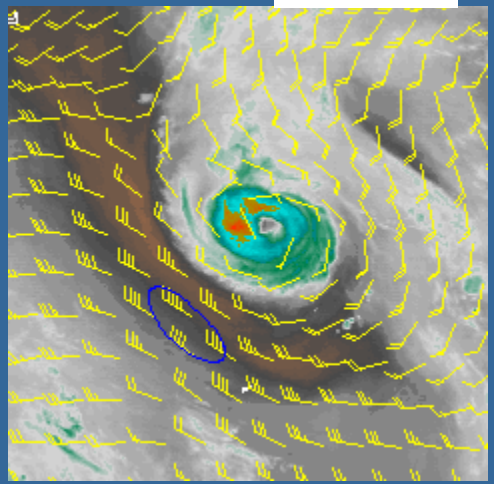
00z 26 Sep 03 OPEN



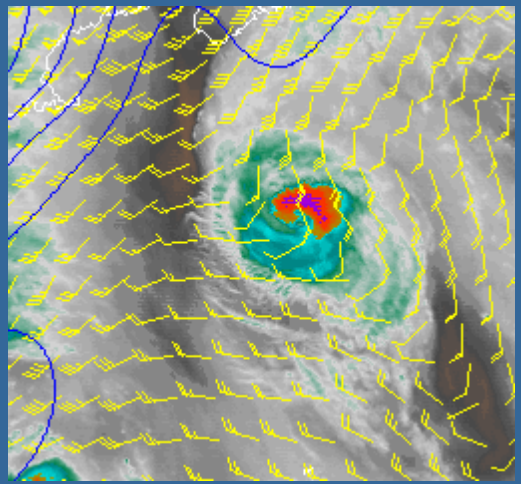
00z 27 Sep 03 CLOSED



09z 27 Sep 03 OPEN



00z 28 Sep 03 CLOSED



12z 28 Sep 03 OPEN

# EVENTS

## Storm Behavior

Right Turns ---------- 153 Events
Left Turns ---------- 79 Events
Eye Structure Changes ----- 47 Events
Intensification Going East - 21 Events
Demise ---------- 33 Events
Early Storm Structure -------19 Events
Lift Out ---------- 9 Events

Storm Behavior Events 361

## Environmental Changes

Ridge Rolls ---------- 120 Events
**Base Surges ---------- 73 Events**
Dry Air Effects ---------- 50 Events
Adjacent System Changes - 76 Events
DZ Formation ---------- 34 Events
**Inside Boundaries ----------23 Events**

Environmental Change Events 376

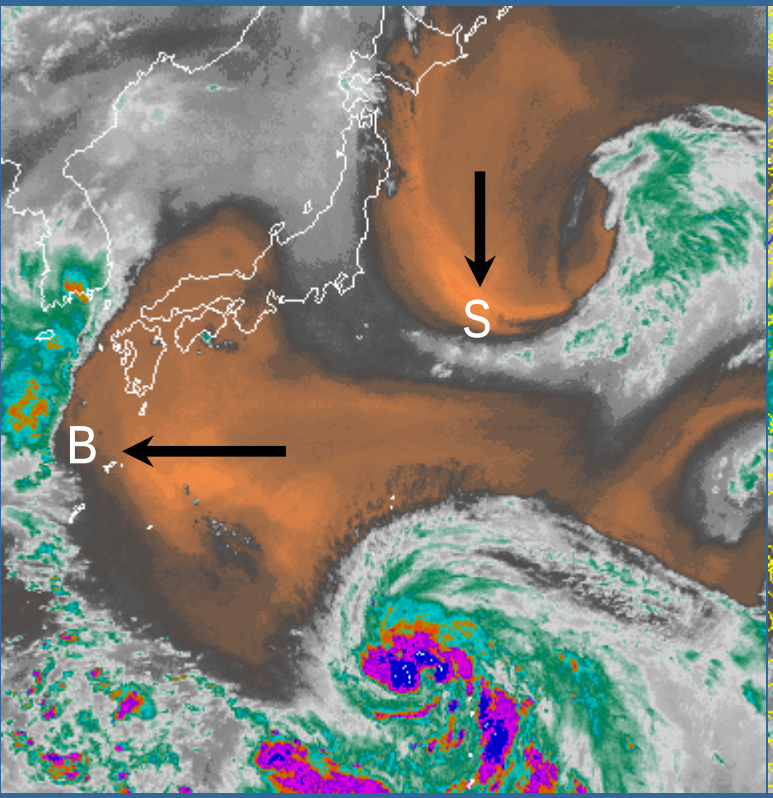
Total Events: 737

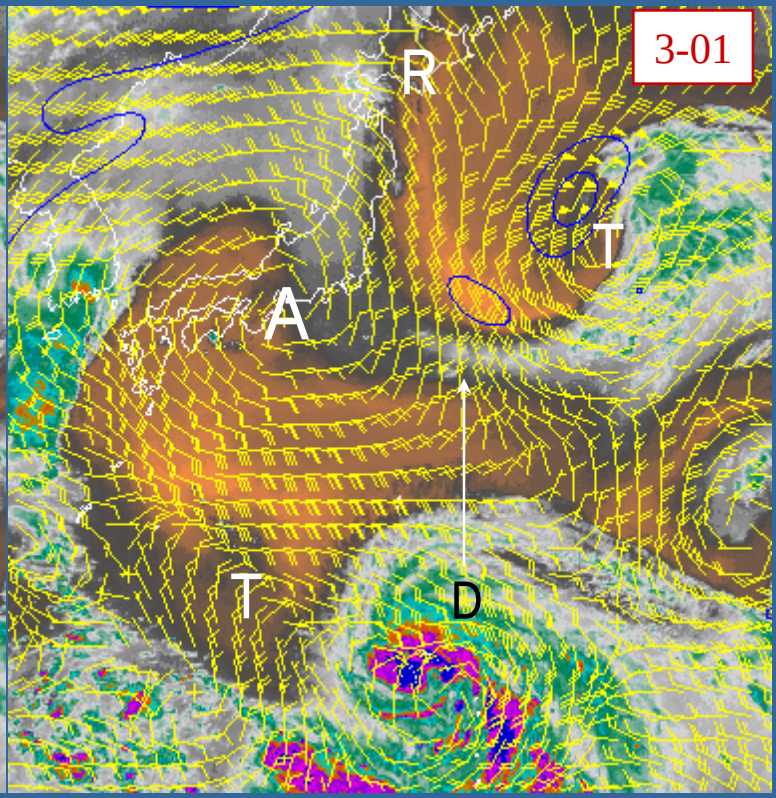
Inside Boundaries: "ER" position favorable for storms. 18 storms either intensified or formed there of the 23 cases (78%).

# Moisture Boundaries

Base Surge Boundaries 73 Events

Inside Boundaries 23 Events



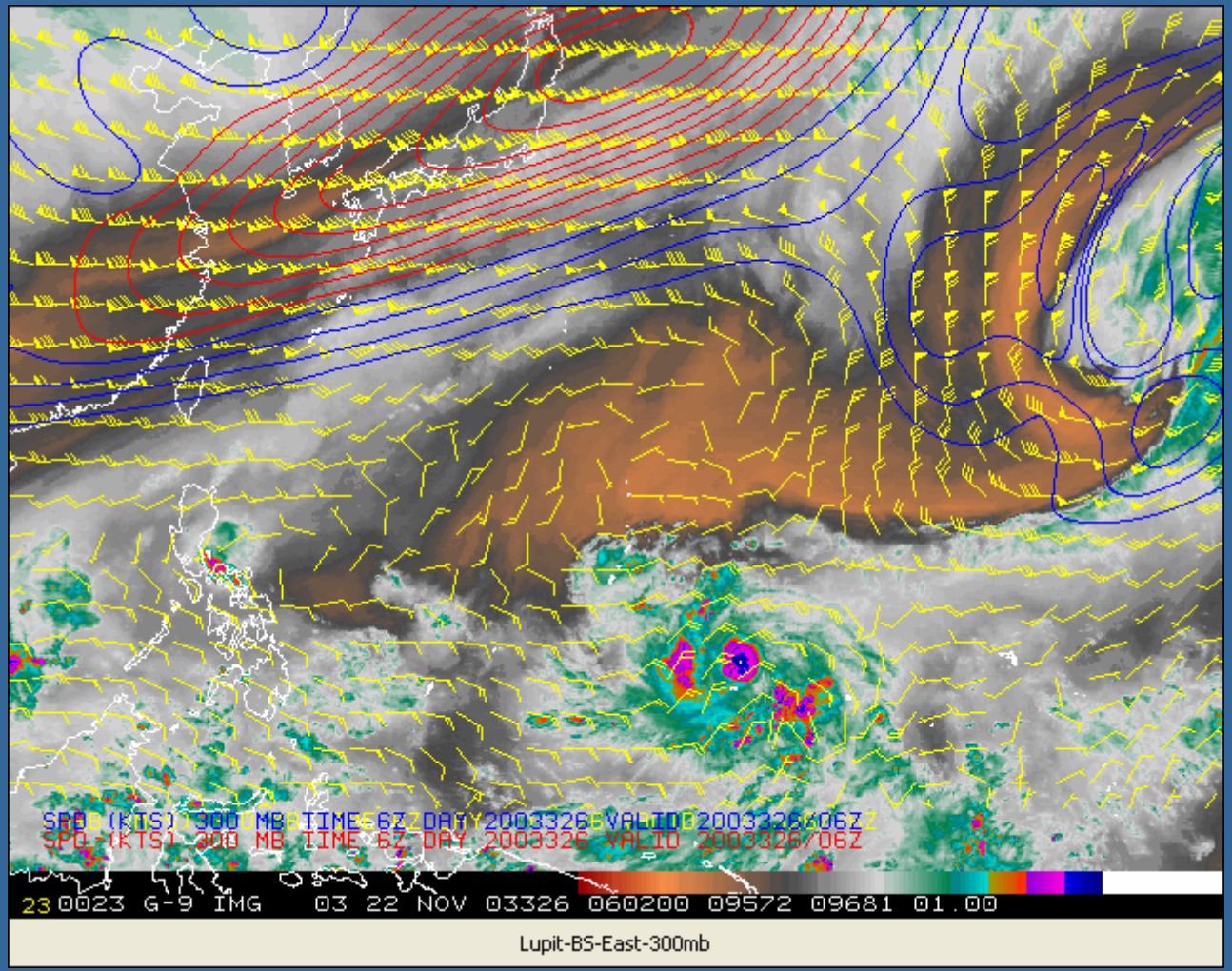




WP-01 Pabuk 0032z 15 Aug 01 Water Vapor

300mb GFS Winds 00z 15 Aug 01

Pabuk at 45 kts intensity moving 290 degrees Base Surge boundary “S” moving southward. Inside Boundary “B” moving westward

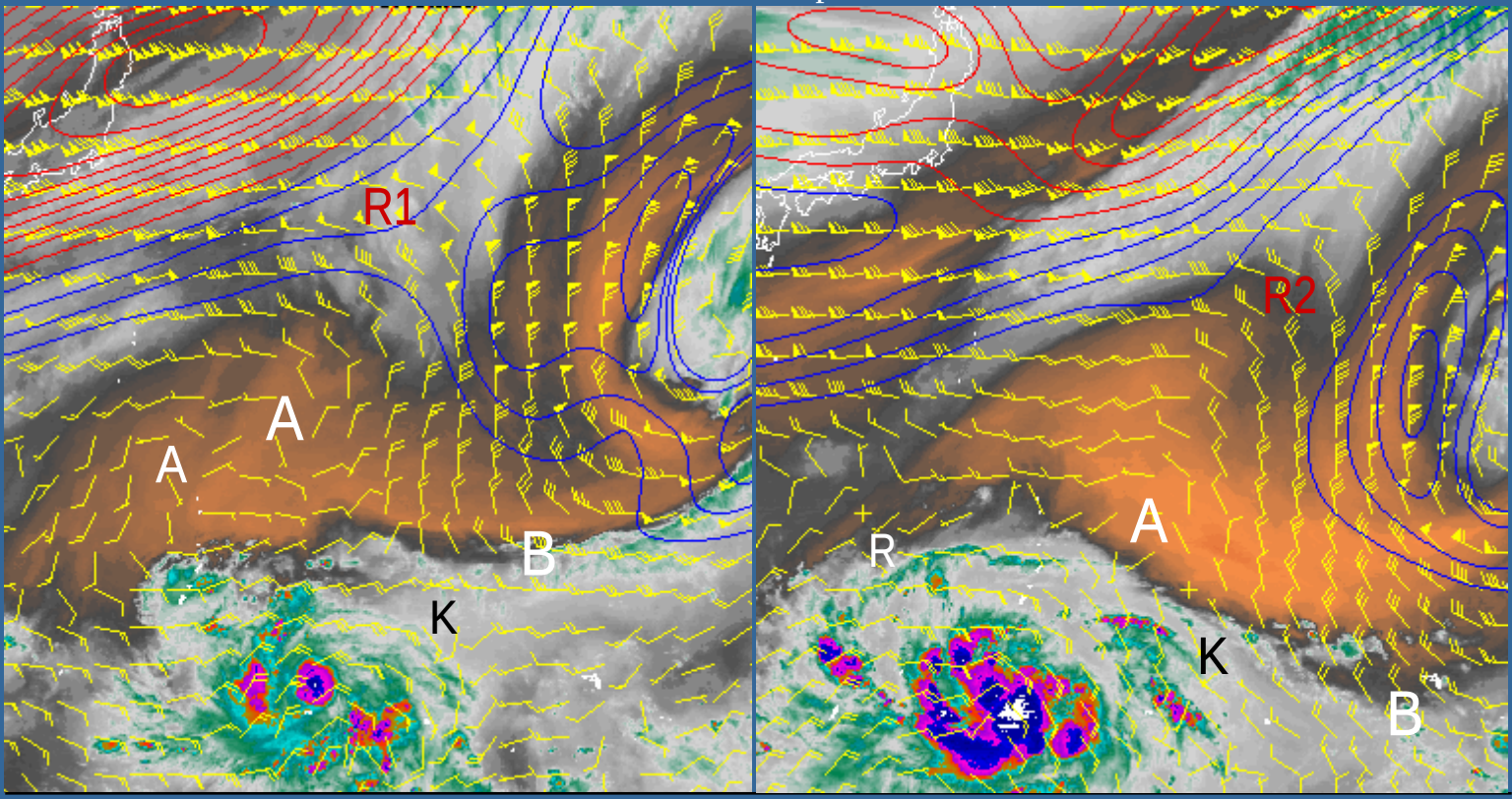
# Base Surge East
# WP-03 Lupit




Lupit 300mb GFS Winds 06z 22 Nov - 18z 23 Nov 03 65 to 95 knots

65 to 95 kts

WP-03 Lupit

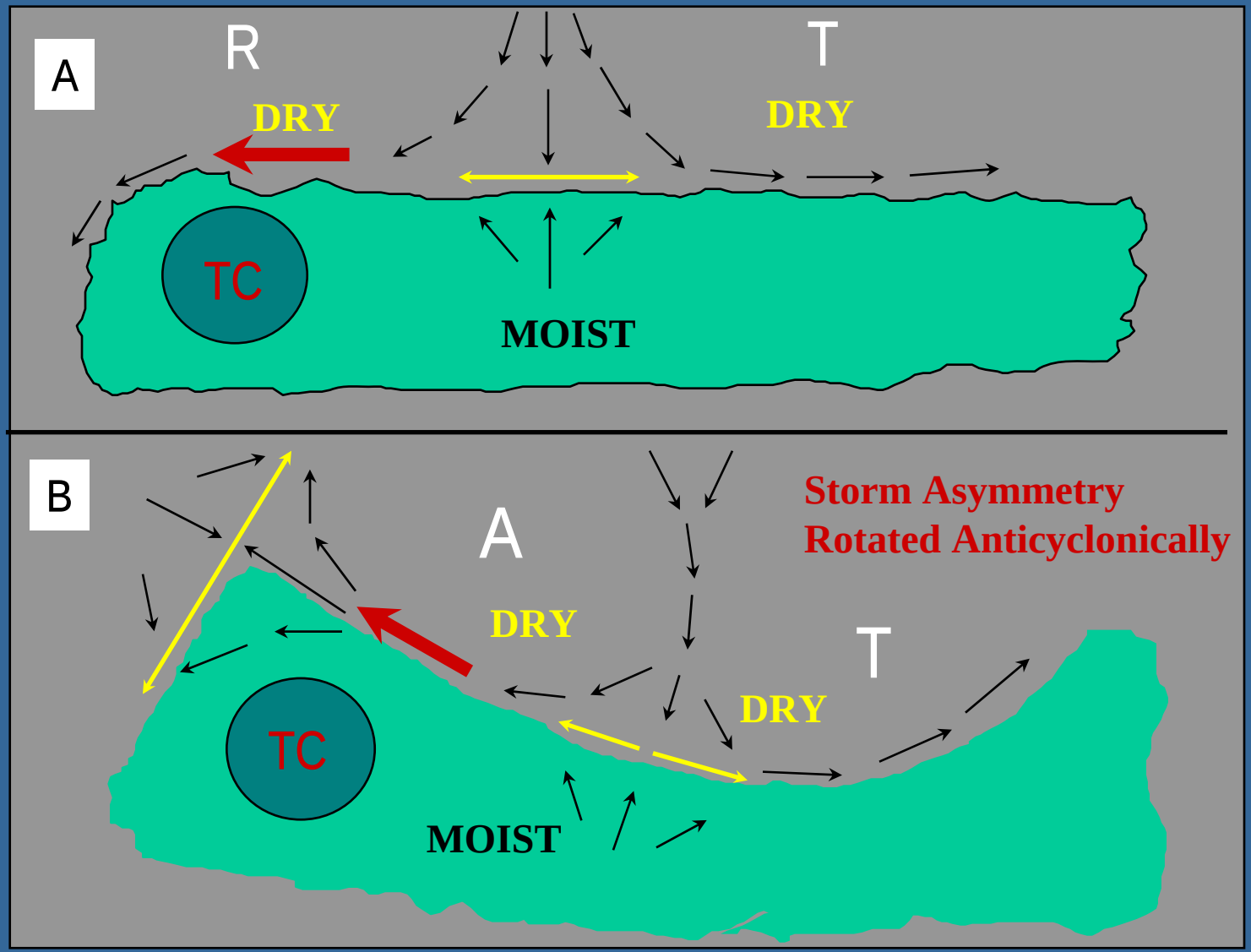


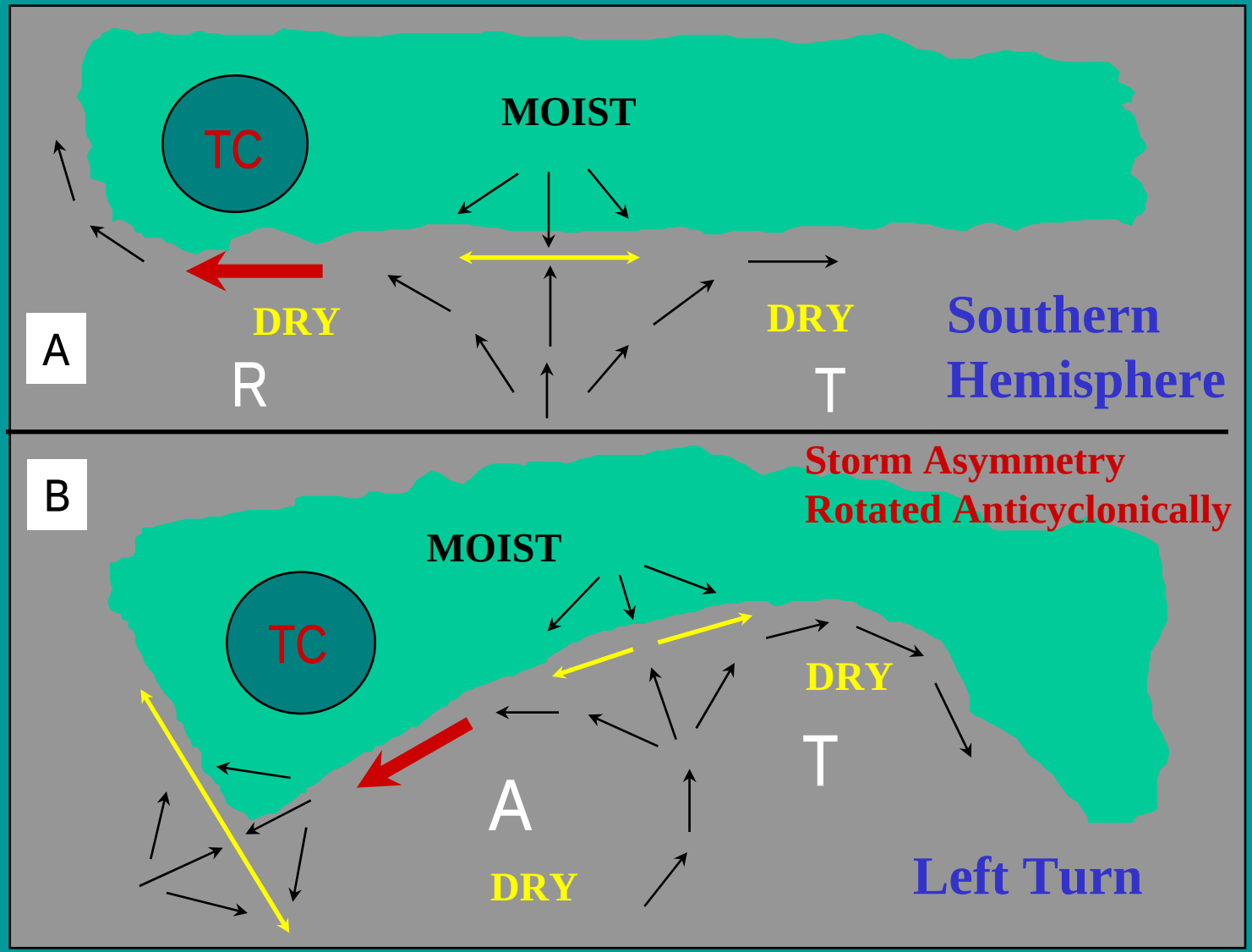

06z 22 Nov 03

300mb GFS Winds

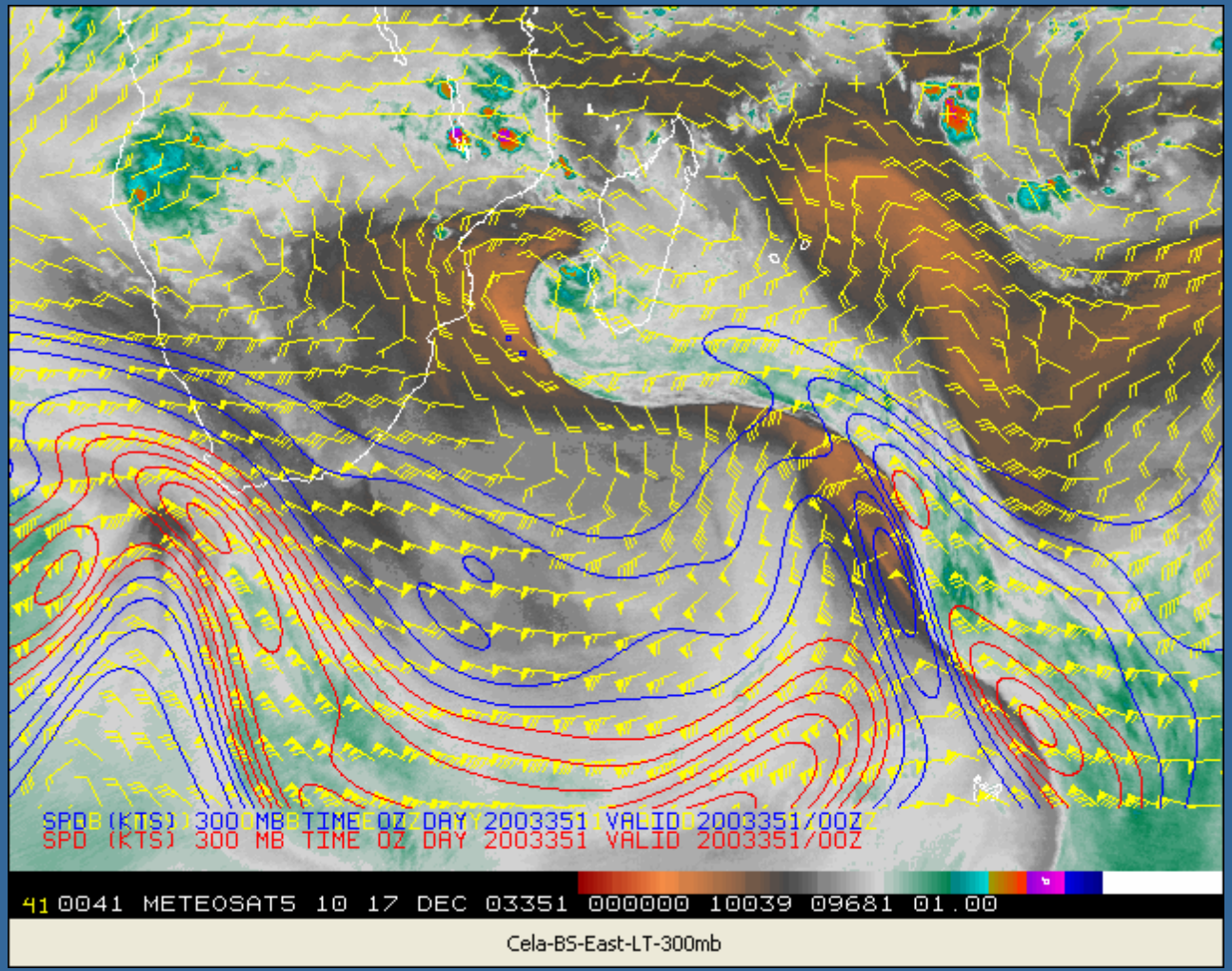
18z 23 Nov 03

Base Surge East Side Anticyclone Moved Equatorward Lupit Intensified 65 to 95 knots. Right Turn 250 to 300 degrees 18z 23 Nov 03

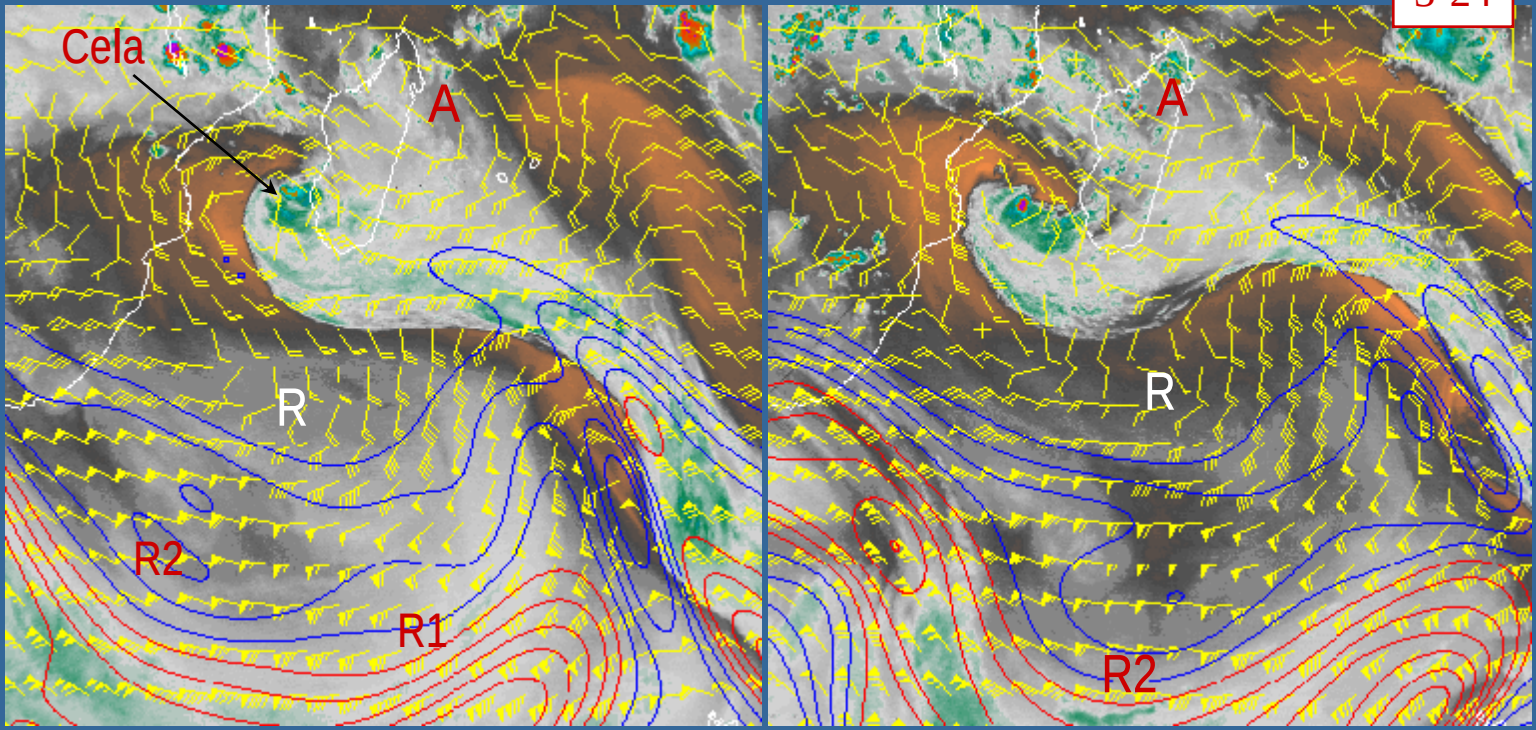

A
R
T
DRY
DRY
TC
MOIST
B
A
Storm Asymmetry
Rotated Anticyclonically
DRY
T
DRY
TC
MOIST


TC
MOIST
DRY
DRY
A
R
T
Southern
Hemisphere
B
Storm Asymmetry
Rotated Anticyclonically
MOIST
TC
DRY
T
A
DRY
Left Turn

# Base Surge East
# SIO-03 Cela




SIO-03 Cela 300mb GFS Winds 00z 17 Dec - 00z 18 Dec 03 Pre Left Turn

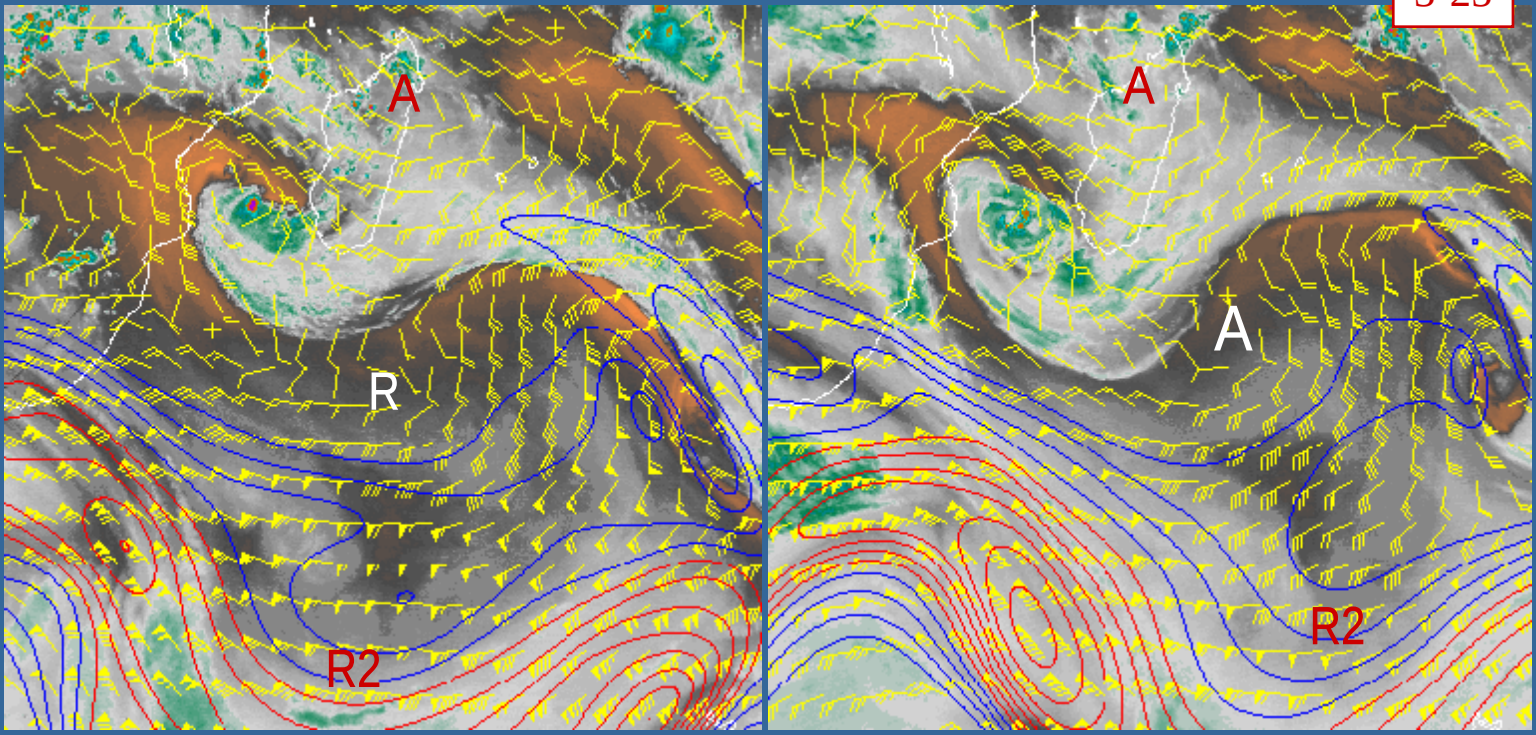



00z 17 Dec 03 300mb GFS Winds 12z 17 Dec 03

Cela moving 210 degrees weakening 60 to 55 kts, local T brings dry air from NW. Ridge Roll starts Base Surge East side

Pre Left Turn Period SIO-03 Cela






12z 17 Dec 03 300mb GFS Winds 00z 18 Dec 03

Cela holds intensity, as base surge completes. Left Turn 210 to 120 degrees begins at end of the period. Holds at 55 kts during the turn.

# 73 Base Surge Events

Base Surge - Direct 13 Events (10 of 13 storms weakened)

Base Surge - West 23 Events (12 storms weakened 11 intensified)

Base Surge - East 37 Events ( 28 storms formed or intensified) (76%)

4 cases of formation

33 Cases with storms already present (24 storms intensified. 73%)

In 28 of the 33 events (85%) Right Turns occurred

15 of the 28 "A" or "R" pushed Equatorward
13 of the 28 "Shield Build" or "Phasing" occurred

# EVENTS

## Storm Behavior

**Right Turns ---------- 153 Events**
Left Turns ---------- 79 Events
Eye Structure Changes ----- 47 Events
Intensification Going East - 21 Events
Demise ---------- 33 Events
Early Storm Structure -------19 Events
Lift Out ---------- 9 Events

Storm Behavior Events 361

## Environmental Changes

Ridge Rolls ---------- 120 Events
Base Surges ---------- 73 Events
Dry Air Effects ---------- 50 Events
Adjacent System Changes - 76 Events
DZ Formation ---------- 34 Events
Inside Boundaries ----------23 Events

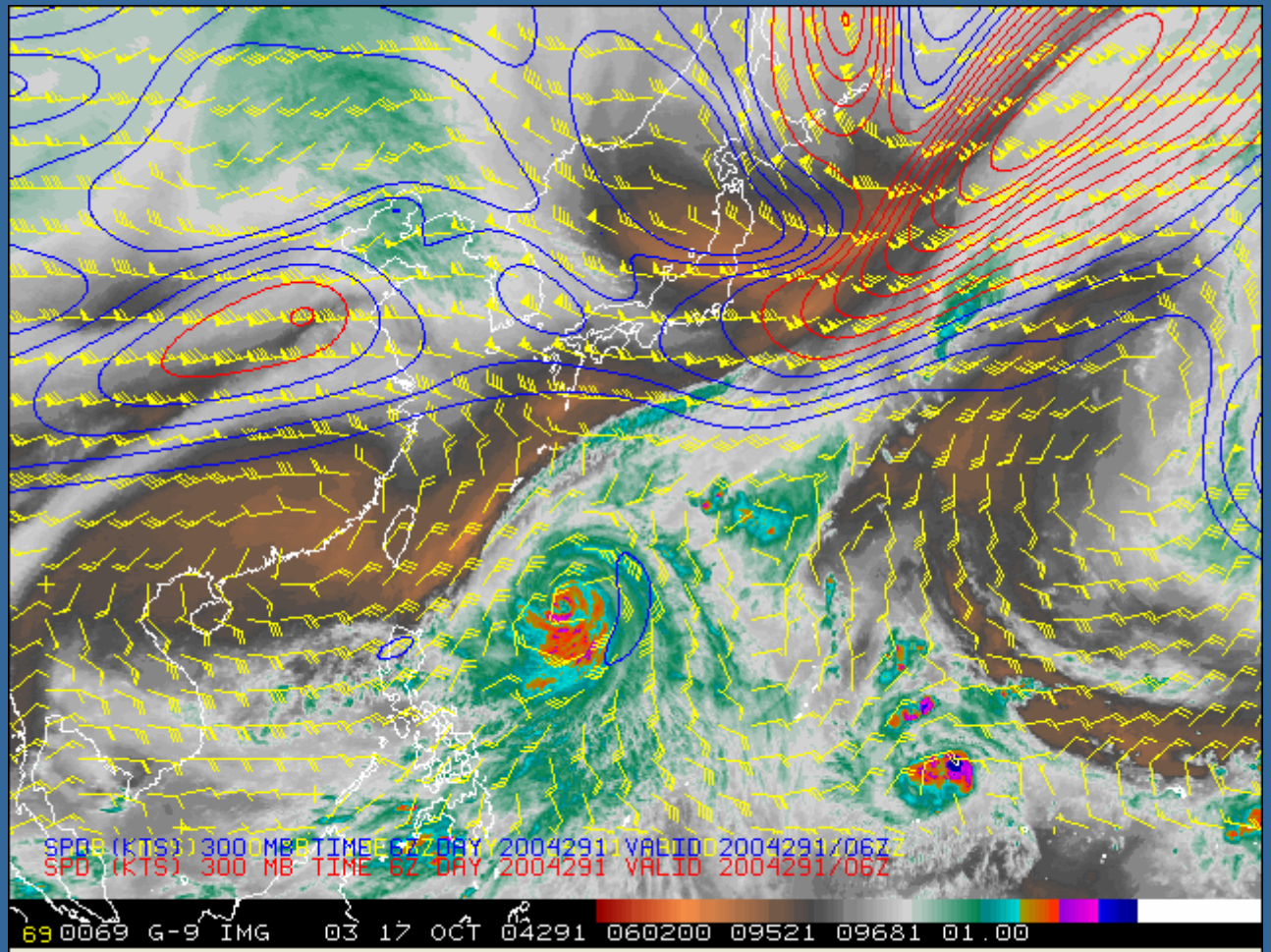
Environmental Change Events 376

Total Events: 737

Includes "Left Turns" in the Southern Hemisphere

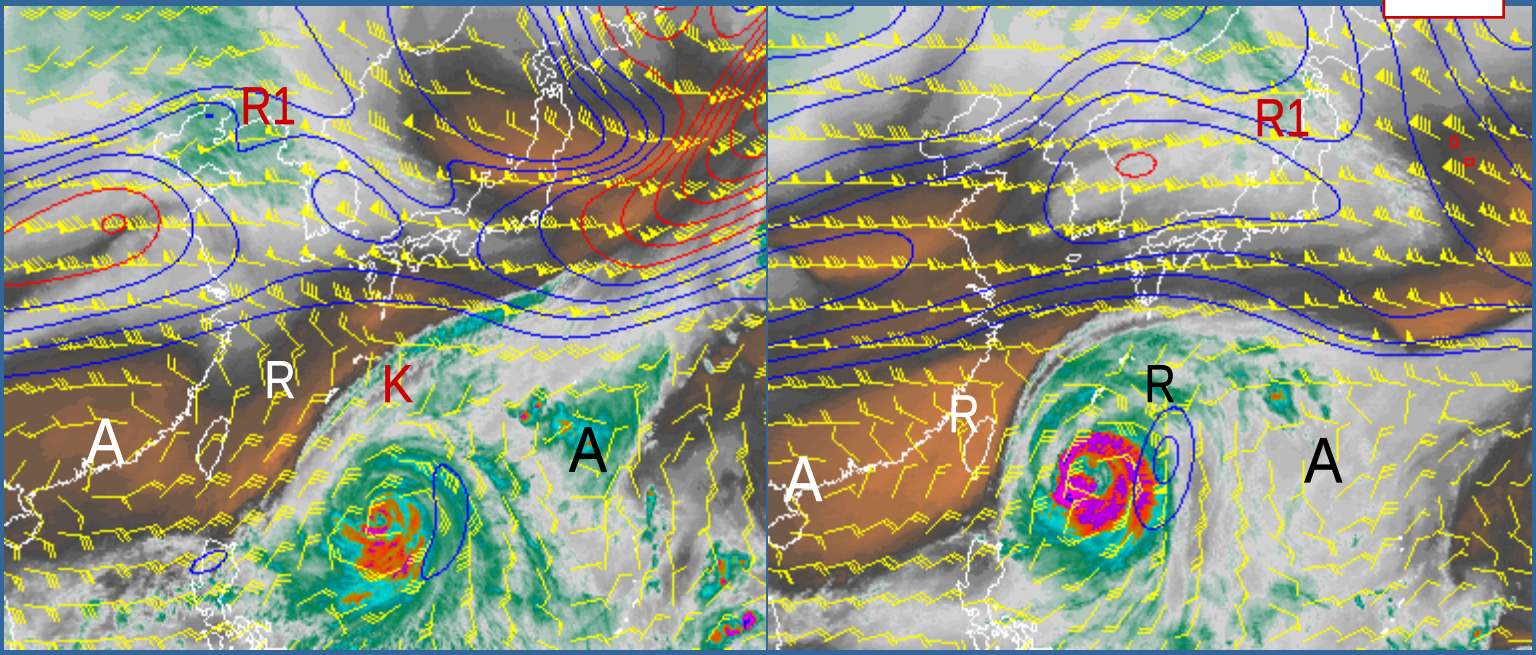
# Right Turn by Ridge Roll

41 Right Turns in this category




WP-04 Tokage 300mb Winds 06z 17 Oct - 12z 18 Oct 04

120 to 100 kts WP-04 Tokage 8-11

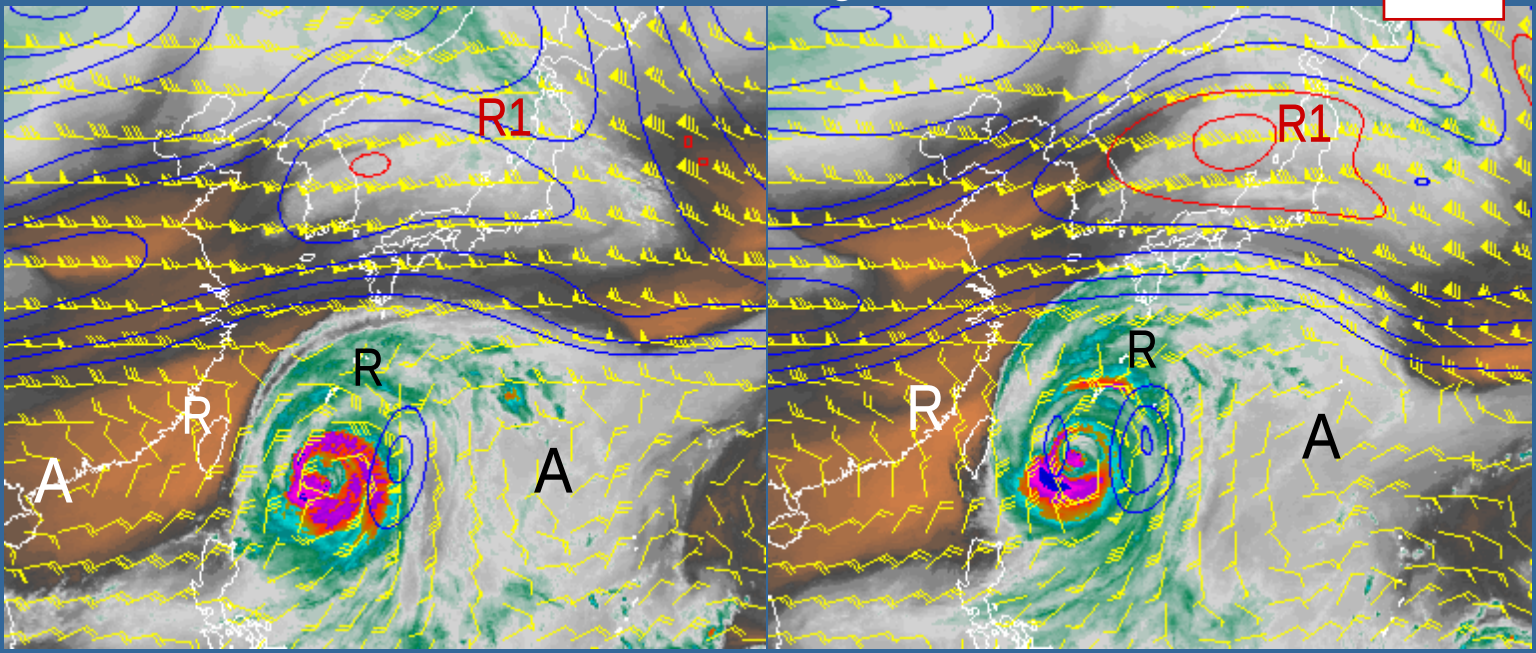



06z 17 Oct 04 300mb GFS Winds 03z 18 Oct 04

Tokage moving 310 degrees. Eye Restructuring. Right Turn begins 03z 310 to 360 degrees

100 to 95 kts WP-04 Tokage

8-12



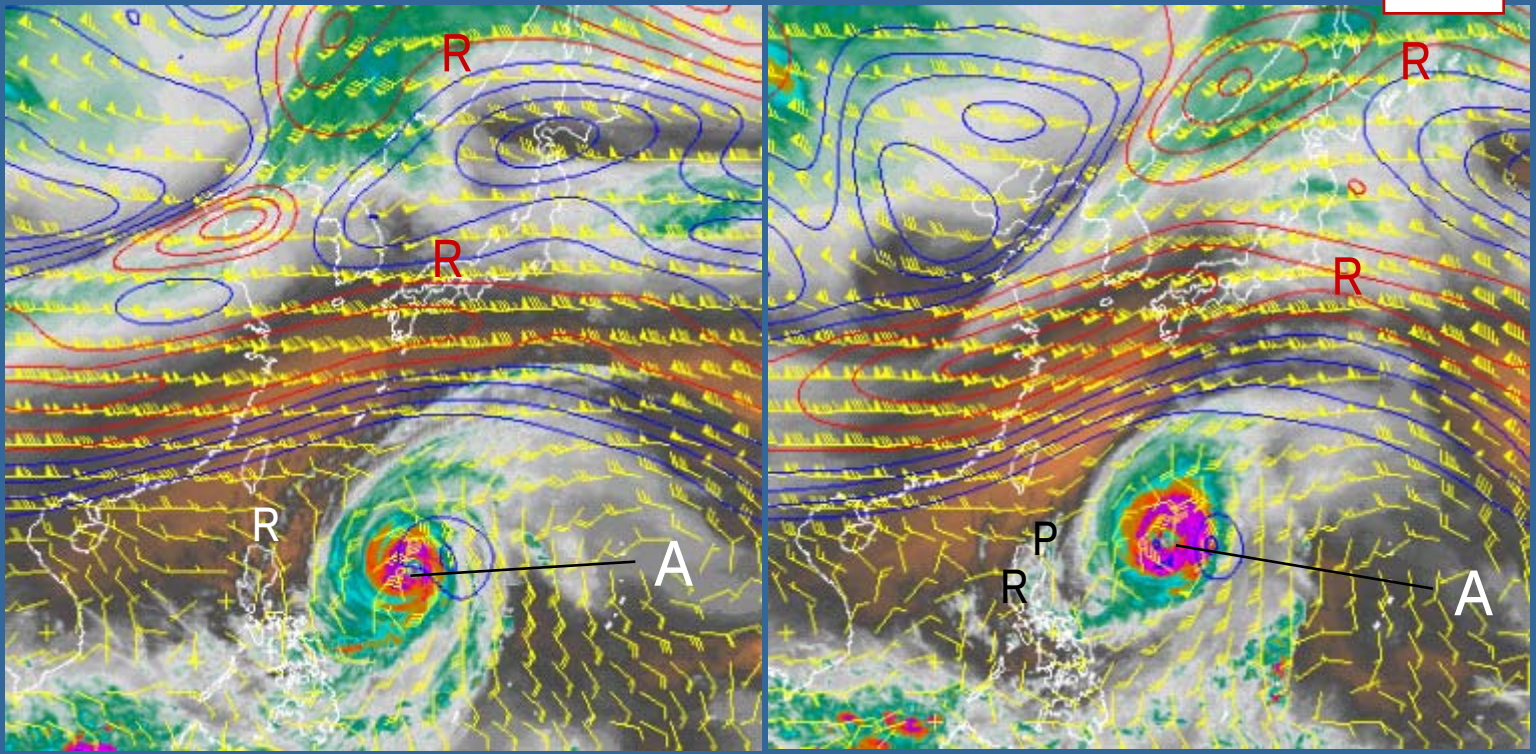

03z 18 Oct 04 300mb GFS Winds 12z 18 Oct 04

Right Turn 310 t0 360 degrees completes. Speed max east side intensified.

# Hybrid Right Turn

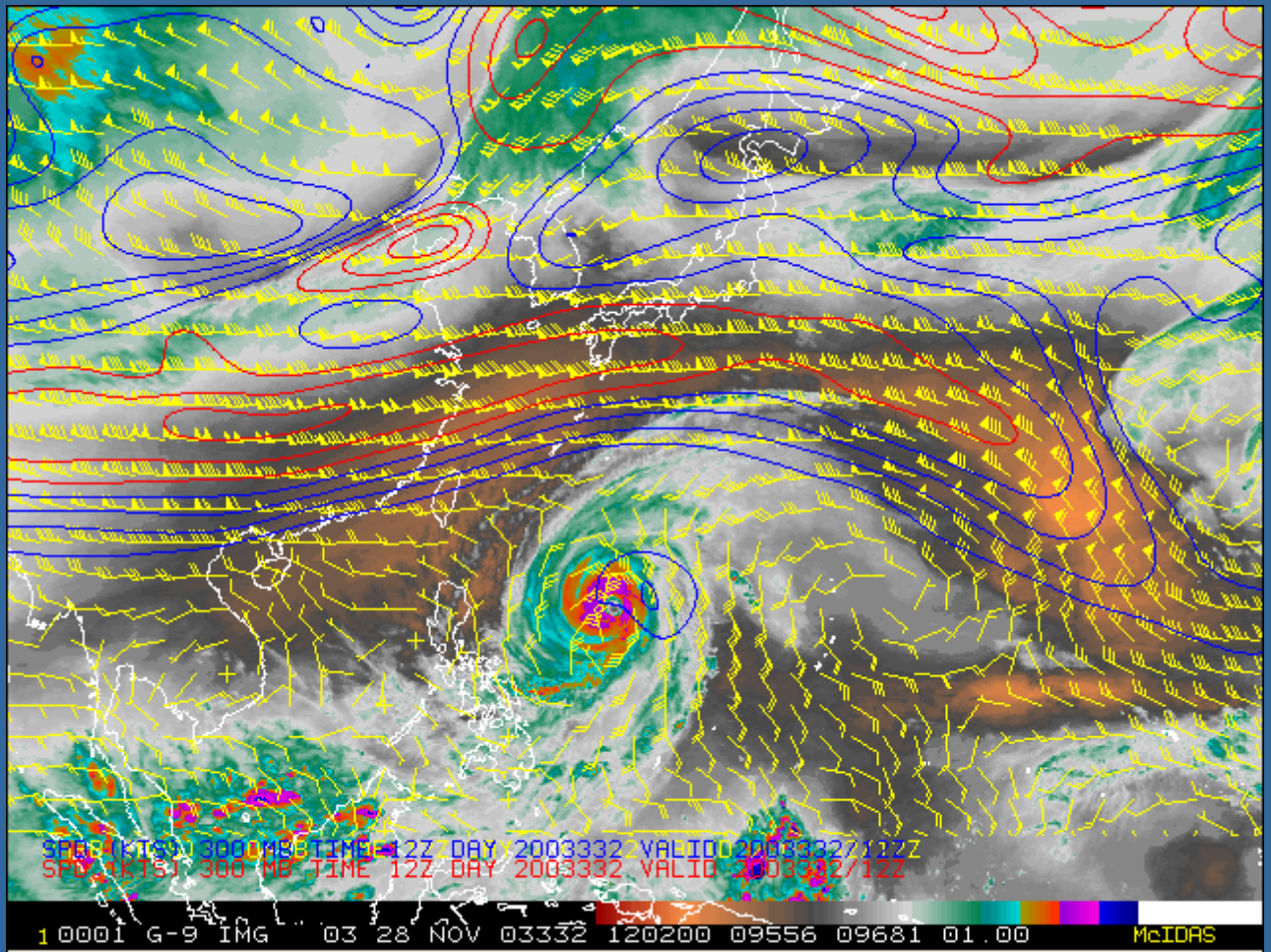
31 Right Turns in this category

P-09 135 to 110 knots WP-03 Lupit 8-05




12z 28 Nov 03 300mb GFS Winds 03z 29 Nov 03

At the end of this period, Lupit turned right 320 to 360 degrees




8-05 WP-03 Lupit LV 300mb Winds 12z 28 Nov - 03z 29 Nov 03

# Right Turn Categories

Digging Troughs West Side ---------- 8 Cases
Hybrid Turns ---------- 31 Cases
Cold Low Interactions ---------- 4 Cases
Total **Right Turns influenced by Troughs** **43**

Ridge Rolls (Intensification or re-positions) ---------- 41 Cases
Ridge or Anticyclone Pushed Equatorward---------- 19 Cases
No Base Surge East Associated
Base Surge, Boundary Rotation East Side ----------28 Cases
Ridge or Anticyclone Pushed Equatorward---15
Shield Build - Phasing---------- 13
Moves around Anticyclone ---------- 7 Cases
Total **Right Turns Influenced by Ridges** **95**

Unusual Turns or Causes---------- 7 Cases
Puzzles ---------- 8 Cases
**15**

**Total - 153 Cases**

# Storm intensity changes with right turns

| Category 7 | Intensified | Held Intensity | Weakened | Intensified plus Held | Total Cases |
|---|---|---|---|---|---|
| **Ridge Rolls** (Sub-set) | 31 (**76%**) 8 (89%) | 3 (7%) | 7 (17%) 1 (11%) | 34 (**83%**) 8 (89%) | 41 (9) |
| "A" Driven Equatorward | 12 (63%) | | 7 (37%) | 12 (63%) | 19 |
| Base Surges E | 12 (43%) | 6 (21%) | 10 (36%) | 18 (64%) | 28 |
| Around "A" | 1 (15%) | | 6 (85%) | 1 (15%) | 7 |
| **Hybrid** | 5 (16%) | | 26 (84%) | 5 (16%) | 31 |
| Digging Troughs | 2 (25%) | | 6 (75%) | 2 (25%) | 8 |
| Cold Low Interactions | 4 (100%) | | | | 4 |

"Puzzles" and "Unusual Turns and Causes" categories, are Not Listed

# Categories of Left Turns and Storm Intensity Changes

7-25

| Event Category 5 | Intensified | Weakened | Held Intensity | Total Events | Average Rating |
|---|---|---|---|---|---|
| Ridge Roll | 16<br>59% | 10<br>37% | 1<br>4% | 27 | 6.81 |
| Digging System | 4<br>22% | 13<br>72% | 1<br>6% | 18 | 6.44 |
| Intensification Adjacent Anticyclone | 6<br>75% | 2<br>25% | 0 | 8 | 5.75 |
| "Col South" | 4 | 1 | 1 | 6 | 7.33 |
| Around Cold Low | 1 | 3 | 2 | 6 | 5.17 |

Average Rating of 65 events in categories: 6.47 Average rating all 79 events 6.01

# Summary and Conclusions

Changes in 6.7μm imagery and 500mb to 300mb Winds are well correlated to Changes in Tropical Cyclone Behavior

Ridge Rolls, Base Surges East Side, Closing Adjacent Systems, Inside Boundaries correlated to Formation and Intensification of Tropical Cyclones

Opening Adjacent Systems and Dry Air Ingests correlated to Storm Weakening

1. CDO Intrusions and possible Eye Replacement Cycles
2. CDO Deforming

Turn Forecasting: Strong Environmental Changes - Can predict the turn
Most cases require quantitative information such as model results

Specific Categories of Environmental Change related to the turn related to intensification or weakening during and after the turn

When Model Results Diverge, Environmental Change Relationships useful in choosing among models, rather than using an ensemble

19 events were shown here. There were 737 events analyzed in study.

| | |
|---|---|
| Rusa WP-02 | Right Turn Digging Trough West |
| Sinlaku WP-02 | Left Turn Digging System |
| Cyclone 2B IND-00 | DZ Formation |
| Adolph EP-01 | DZ Formation |
| Mitag WP-02 | DZ Formation |
| Mitag WP-02 | Ridge Roll Formation |
| Isabel TA-03 | Ridge Roll |
| | Left Turn |
| Phanfone WP-02 | Dry Air Effects |
| | CDO Restructuring |
| Meari WP-04 | Dry Air Effects |
| Juan TA-03 | Adjacent Systems Changes |
| Pabuk WP-01 | Inside Boundary Formation |
| Lupit WP-03 | Base Surge East |
| | Right Turn |
| Cela SIO-03 | Base Surge East |
| | Right Turn (LT - S.H.) |
| Tokage WP-04 | Right Turn (Ridge Roll) |
| Lupit WP-03 | Right Turn (Hybrid) |

Shown by 1 figure only

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Numbers listed in black: Events not addressed in the report

# Last Slide