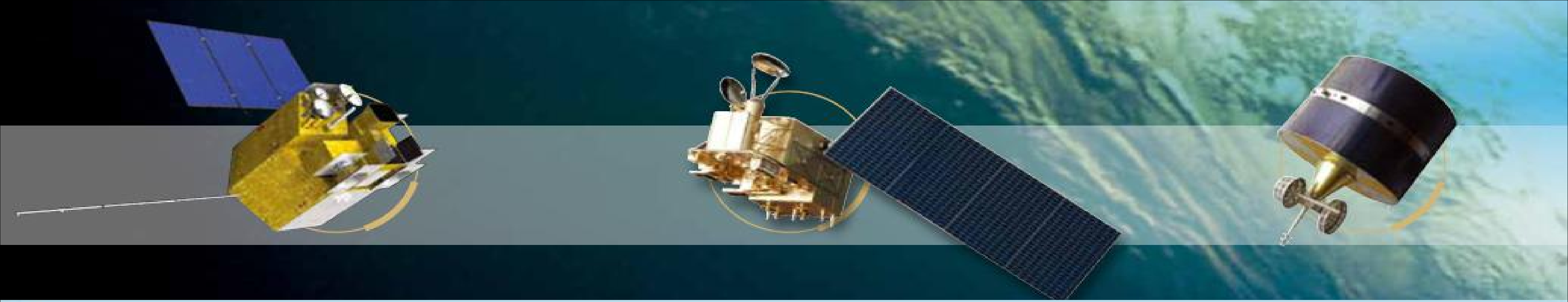


The Satellite Methods for Tropical Cyclone Analysis

Xiang FANG

National Satellite Meteorological Center,

China Meteorological Administration

(NSMC/CMA)

outline

- FY-4 products using in Typhoon monitoring
- The Operational Methods in TC Analysis （DEVORAK Technique）
- FY Satellite data use in Asian summer monsoon monitoring and analysis
- Tropical cyclone analysis using microwave satellite imagery

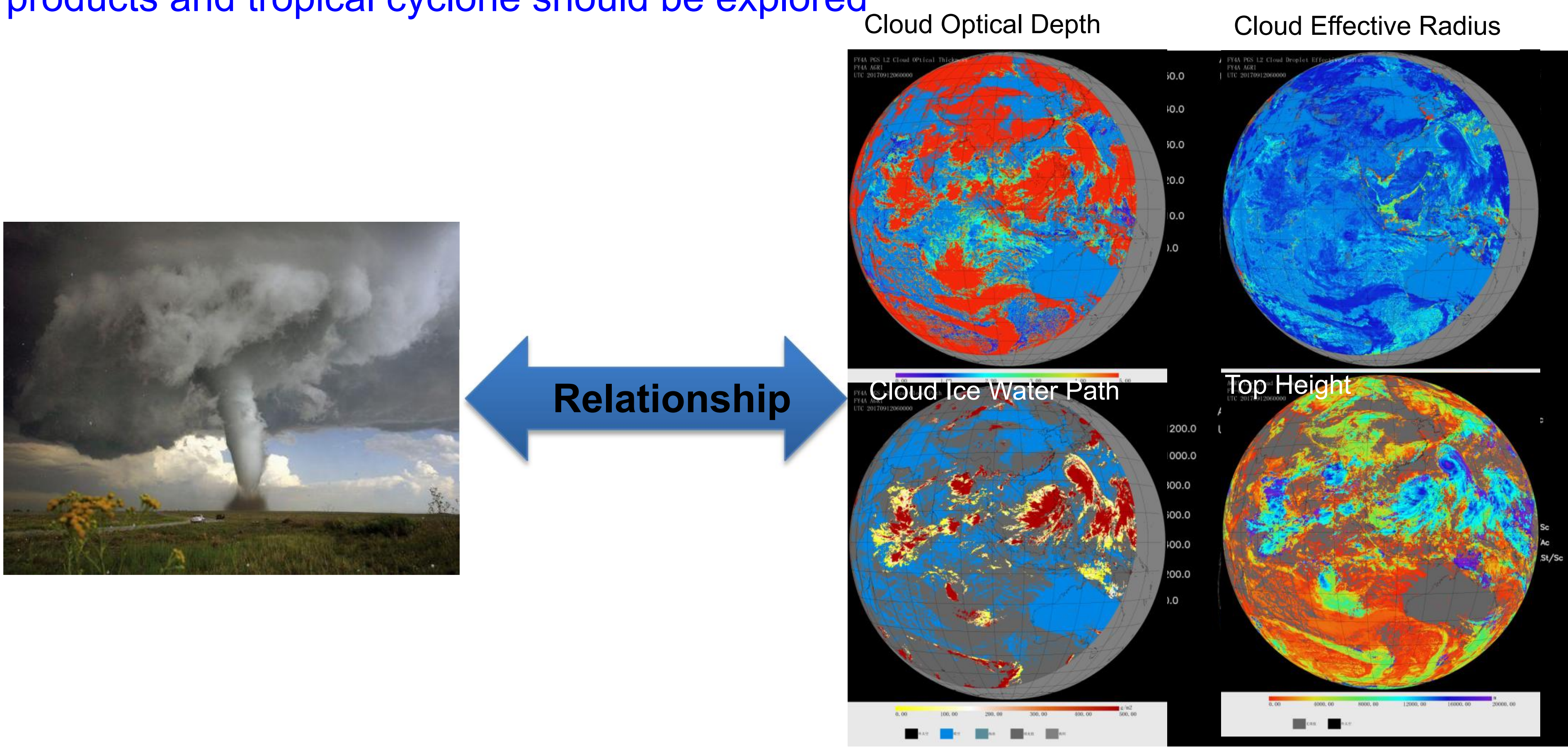
1. FY-4A products using in Typhoon monitoring

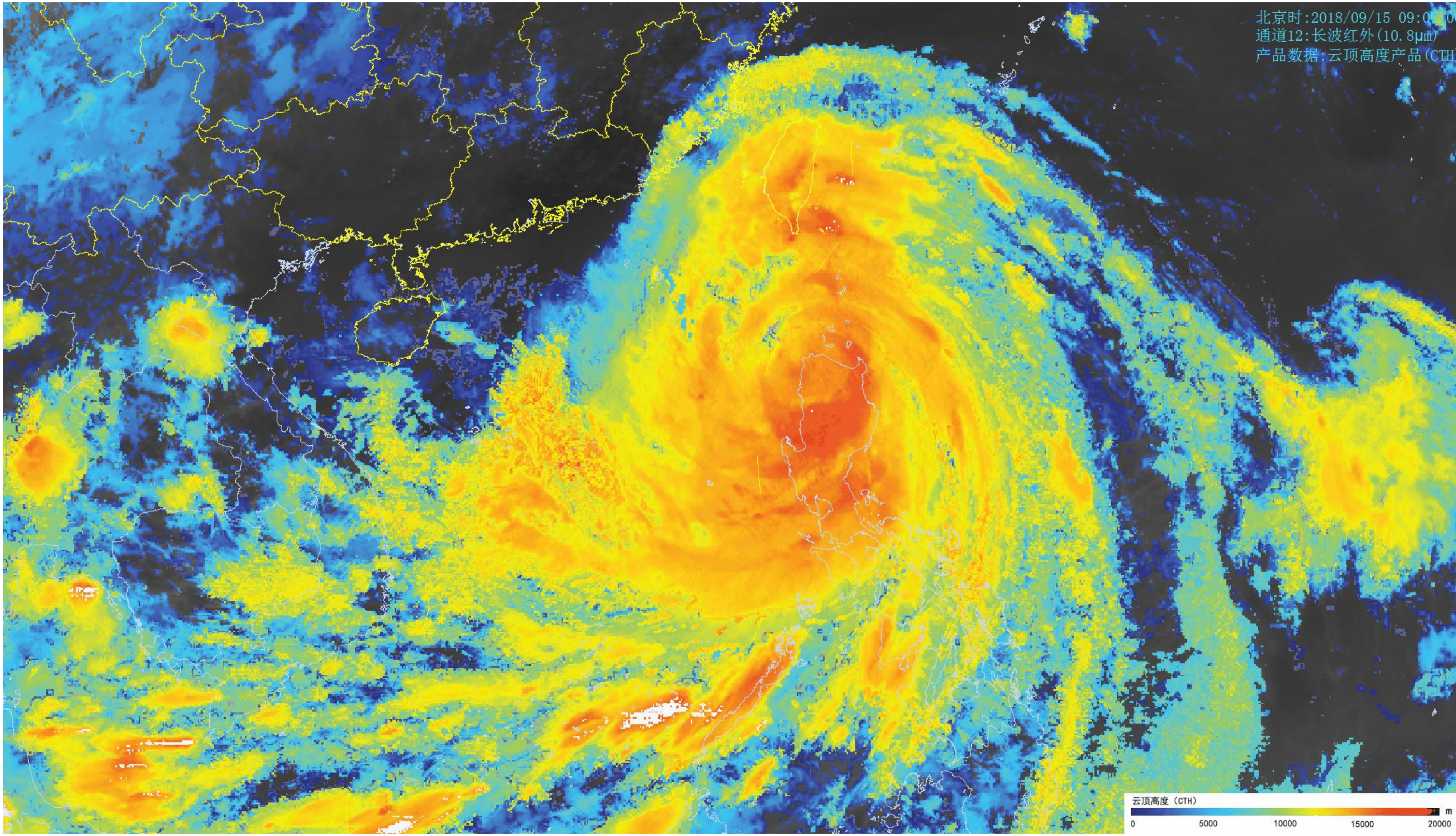
Sensor	Products
AGRI	Cloud type
	Cloud phase
	Cloud pressure/height/temperature
	Atmospheric motion vector
	Convective initiation
	Tropopause folding（water vapor image）
GIIRS	Temperature profile
	Water vapor profile
	Instability index (K/SI/TT/CAPE)
LMI	Lightning detection
	Lightning Jump Identification

Relationship between Cloud products and Tropical cyclone

The optical and microphysical cloud products from FY-4 is released every 1 hour, while those of the previous Chinese meteorological satellite is daily.

To which extent that we could benefit from the more frequent observation on nowcasting is unknown. To this end, the relationship between more frequent cloud products and tropical cyclone should be explored





After the landing of Typhoon "mangkhut", the height of the cloud top was significantly reduced, and the intensity of typhoon weakened.

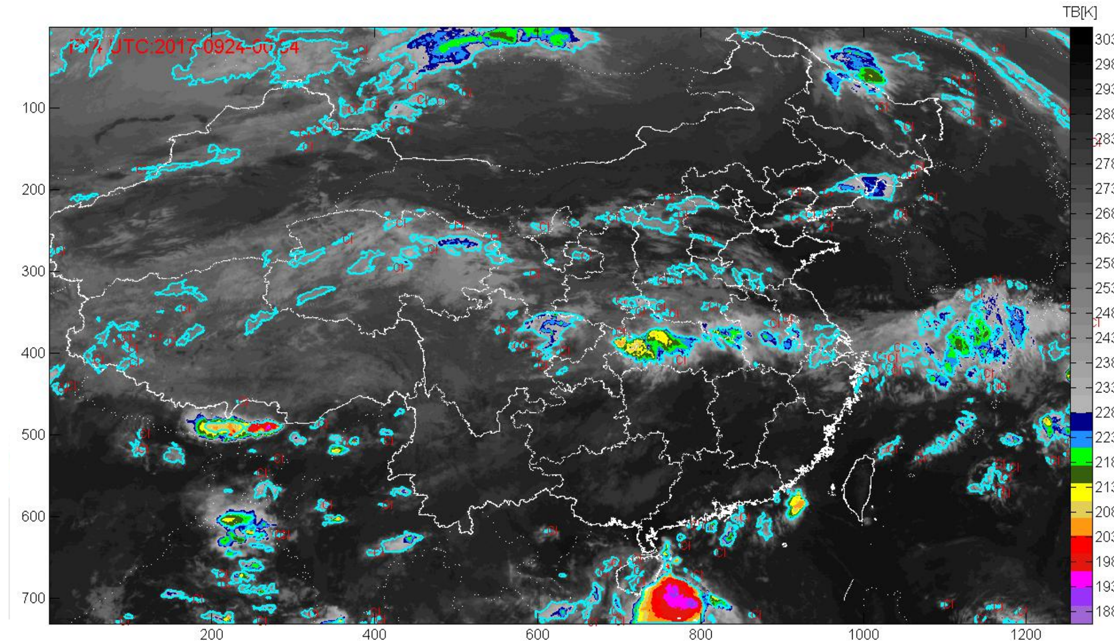
FY-4 **Convective Initiation(CI)** and **Mature Convection** detection

1.Convective targets Identification → **2.Multi Targets Trace** → **3.Cloud Top Cooling Rate**

Method

- Detect rapid cloud top cooling rate use 10.8μm Tb. Box-averaged method (Sieglaff et al., 2010)
- Use muti-channel tests. Multi-channel tests with reference of MB06 (Mecikalski and Bedka, 2006) and GOES-R CI ATBD:
  - ✓ BTD=6.2μ-10.8μ
  - ✓ BTD=6.2μ-7.1μ
  - ✓ BTD=8.5μ-10.8μ
  - ✓ BTD= (8.5μ-10.8μ)-(10.8μ-12.0μ)
  - ✓ BTD=12.0μ-10.8μ
  - ✓ BTD=13.5μ-10.8μ

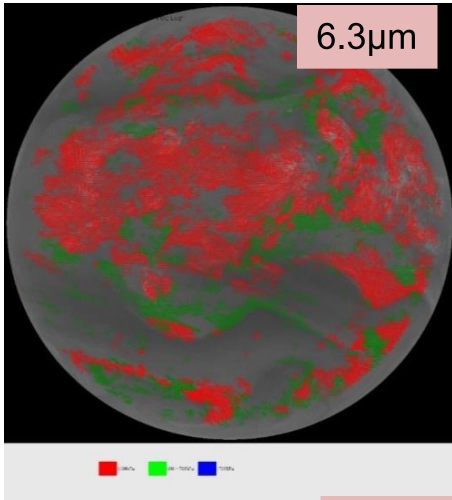
CI from FY-4A regional observation mode (~5min)

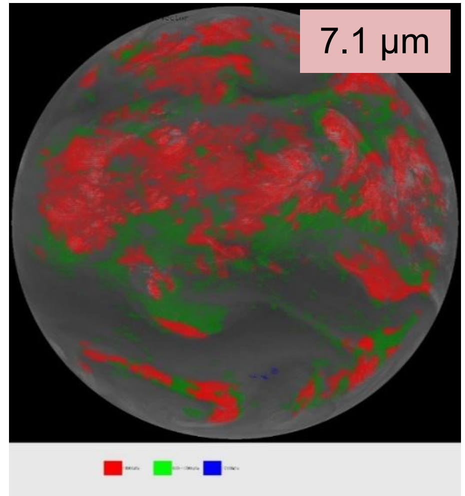


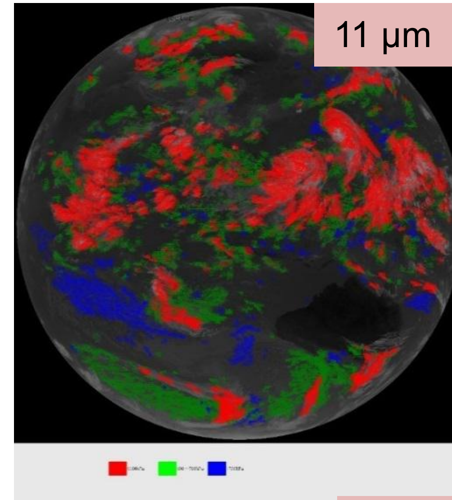
The detection of convective initiation (label CI) on 24 Sep 2017

FY-4A AMV products from AGRI

FY4A



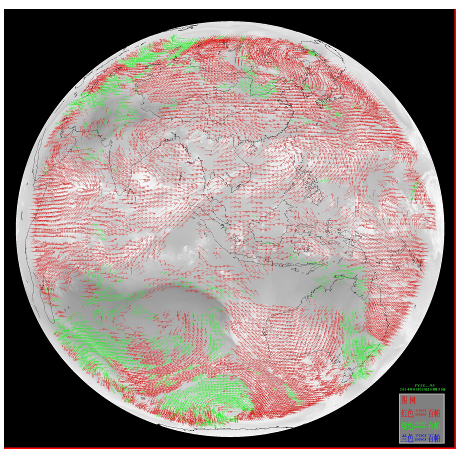


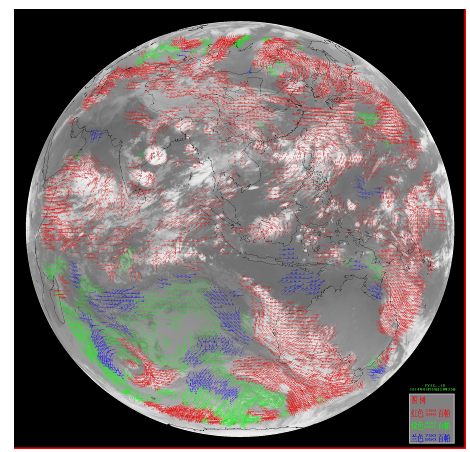


6.3 μm

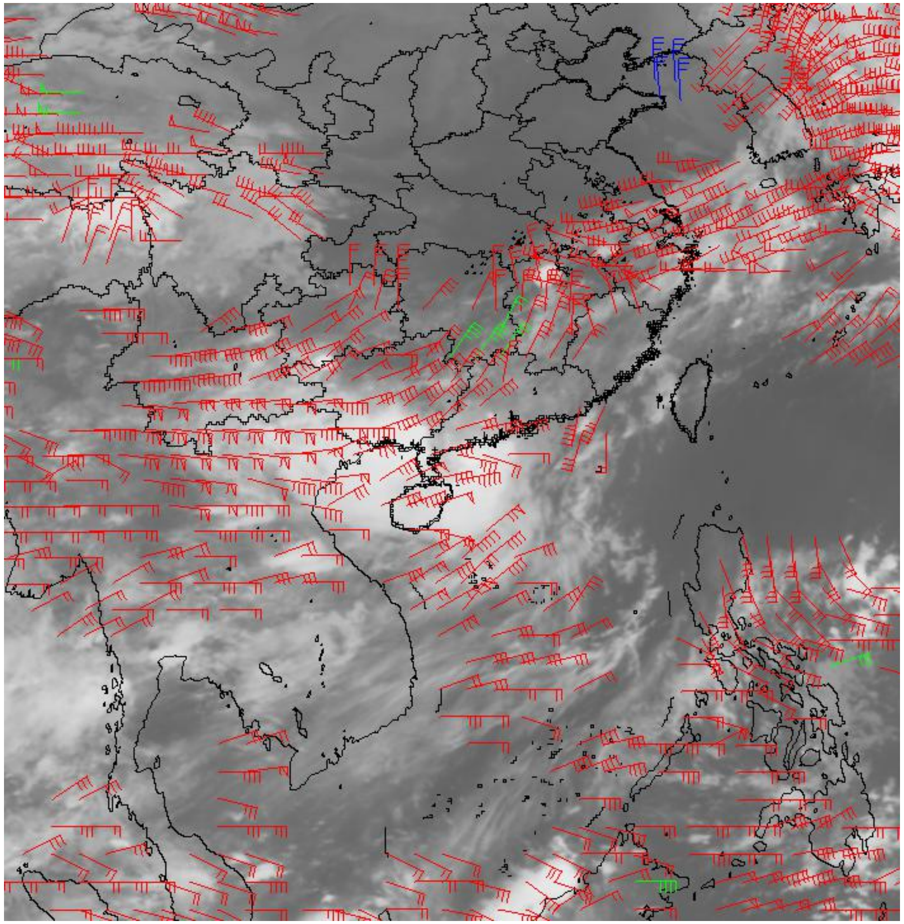
11 μm

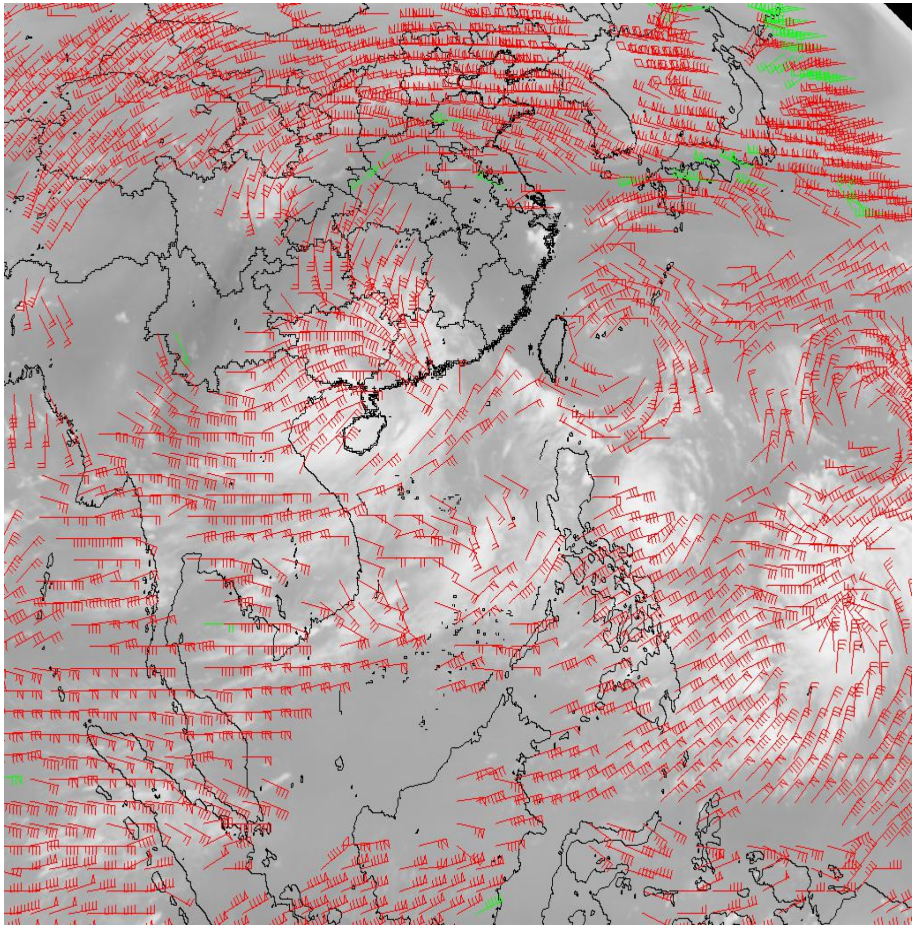
FY2G





Satellite wind are derived from three **successive** images



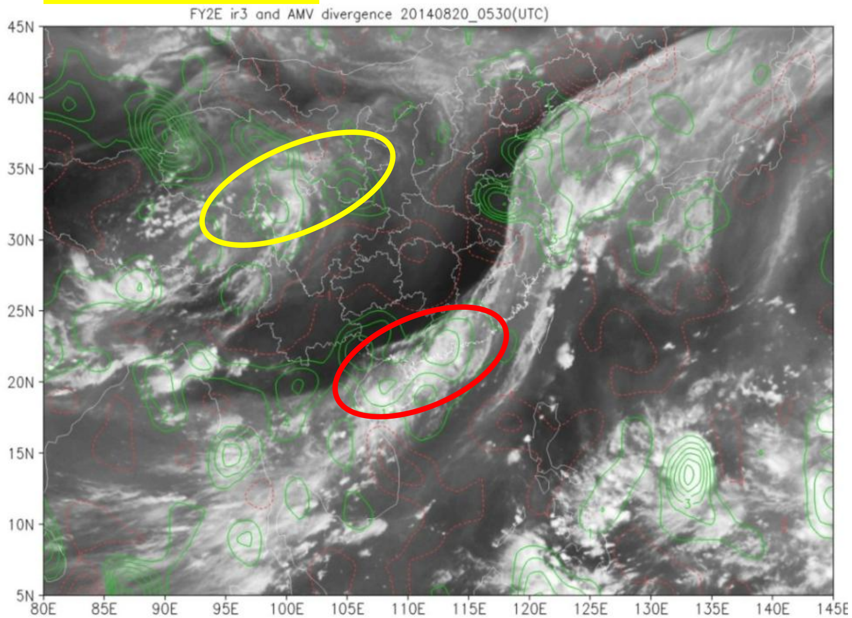


Nuri 23,08,2008 satellite wind

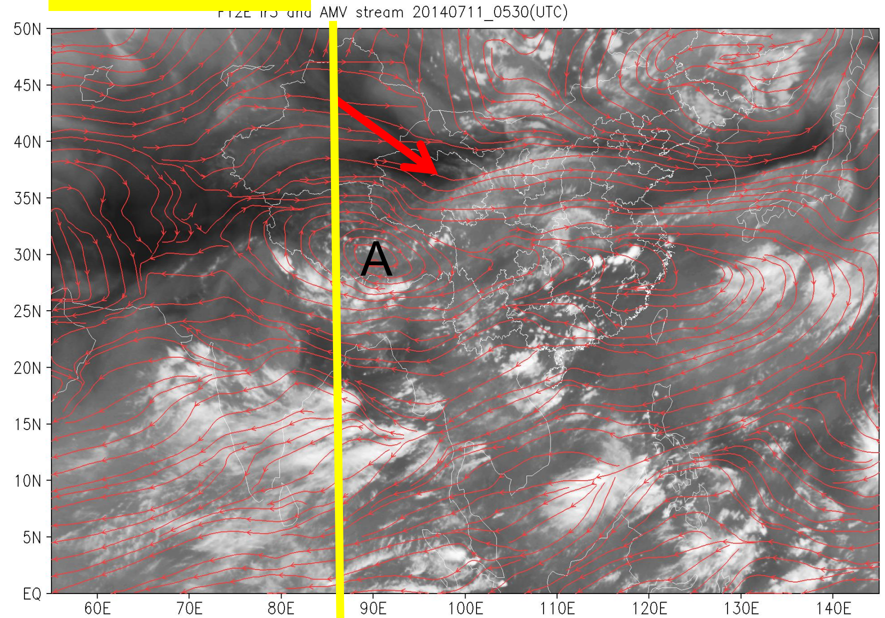
Windward convergence at the upper level, causing the airflow to sink ,which is not conducive to the maintenance of the TC intensity.

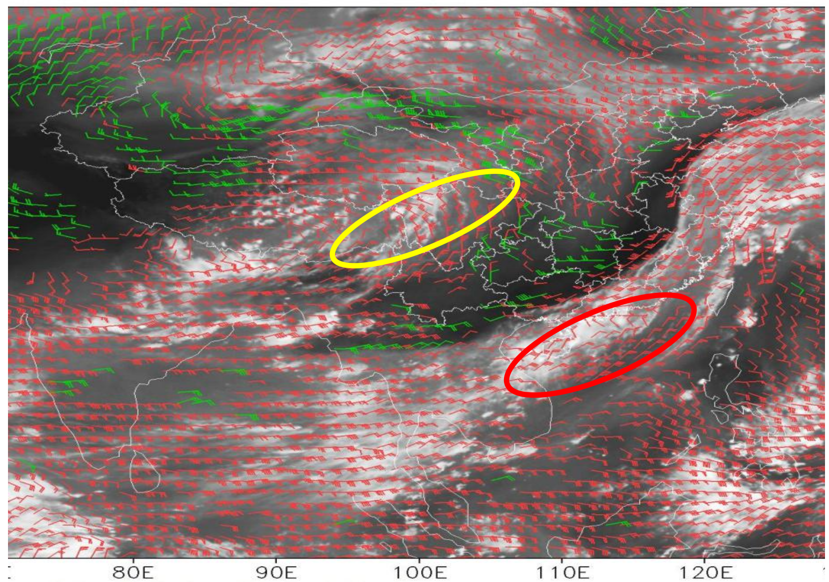
Hagupit 24,09,2008

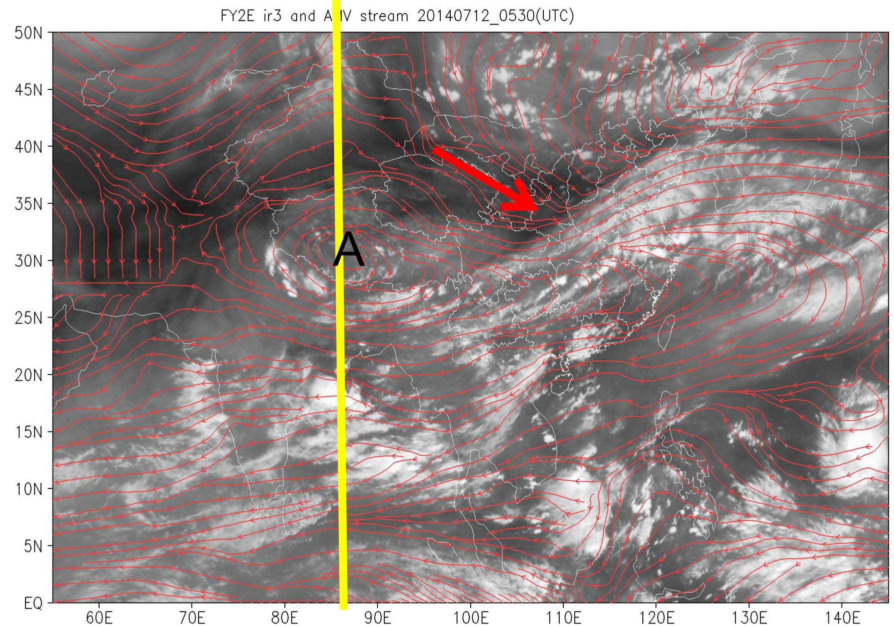
There is obvious wind direction divergence at the upper level, which is conducive to the development or maintenance of the TC intensity divergence



streamline





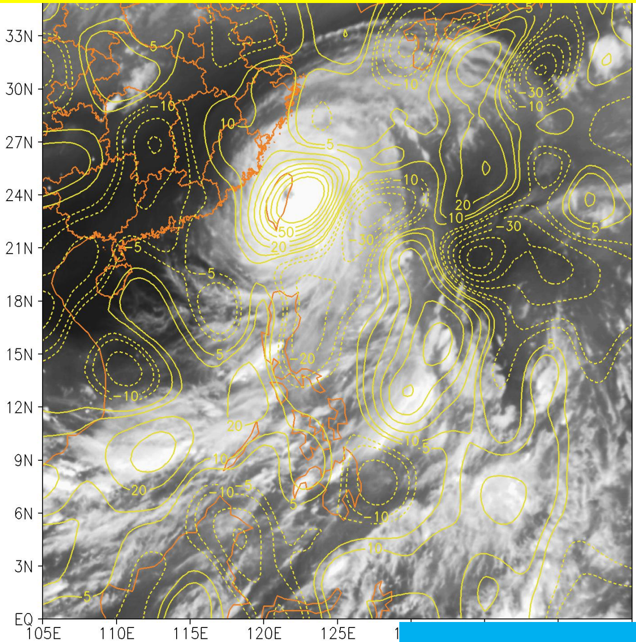


wind

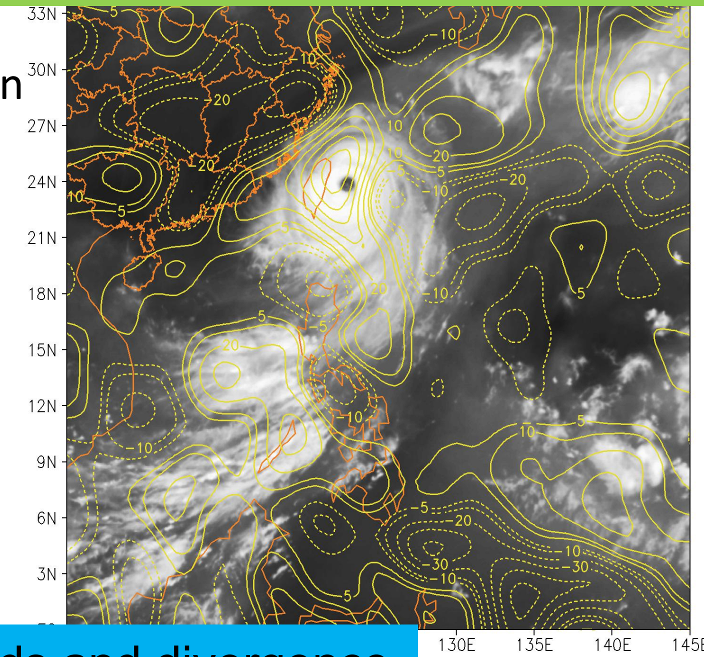
The upper –layer div and streamline are also caculated

27th Sep,201613:30 “Megi”

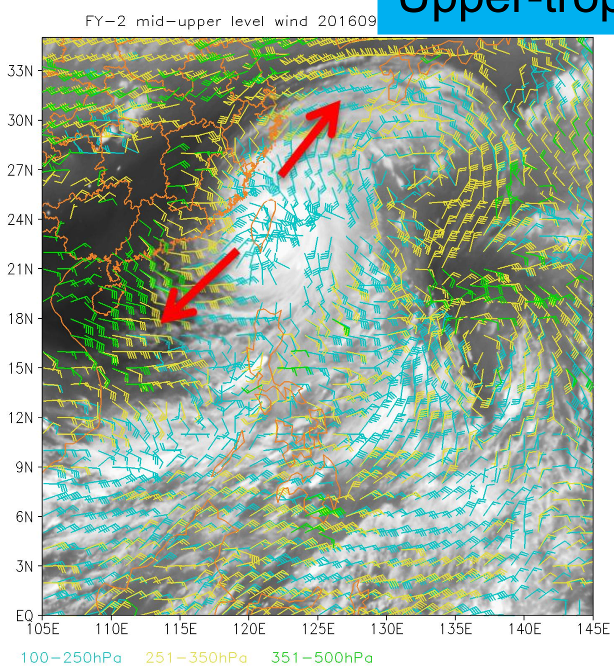
28th Sep.,2015日13:30 “Dujuan”



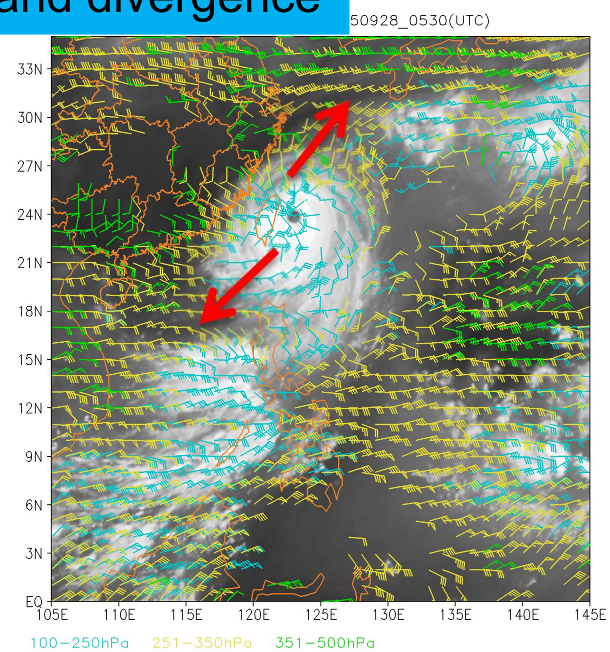
Super Typhoon



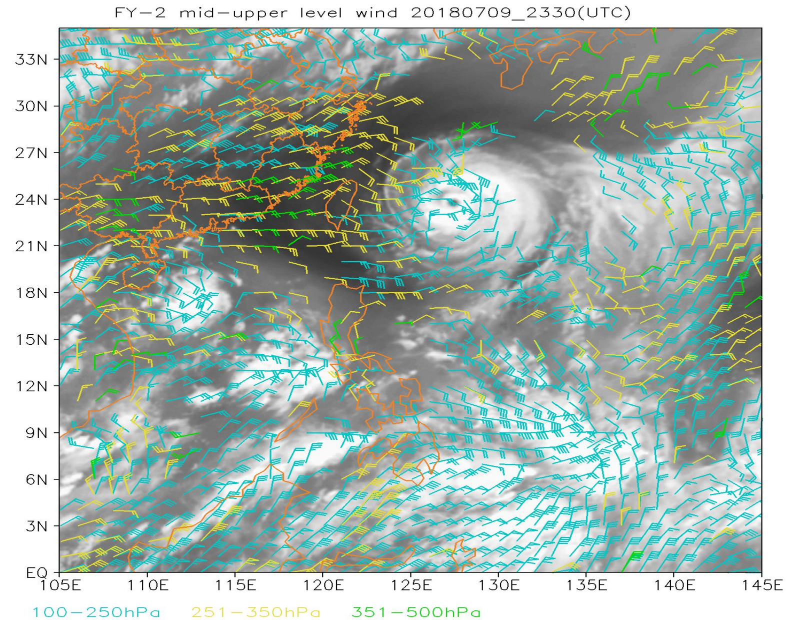
Upper-troposphere Winds and divergence

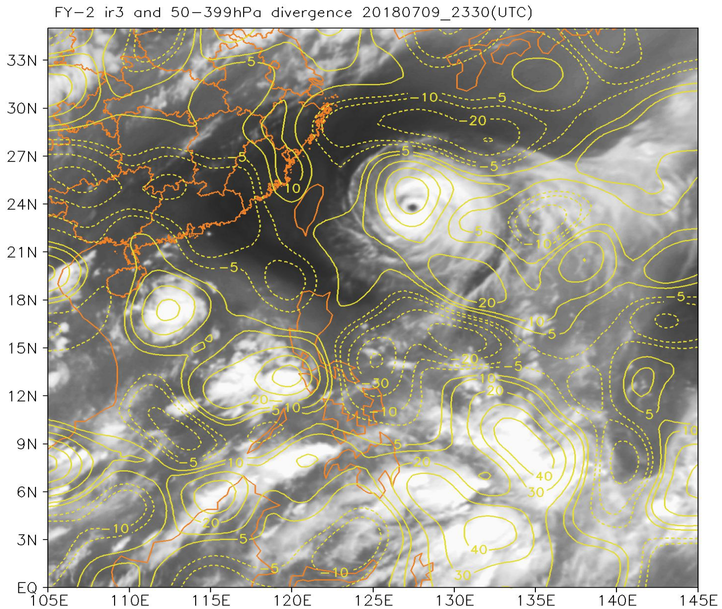


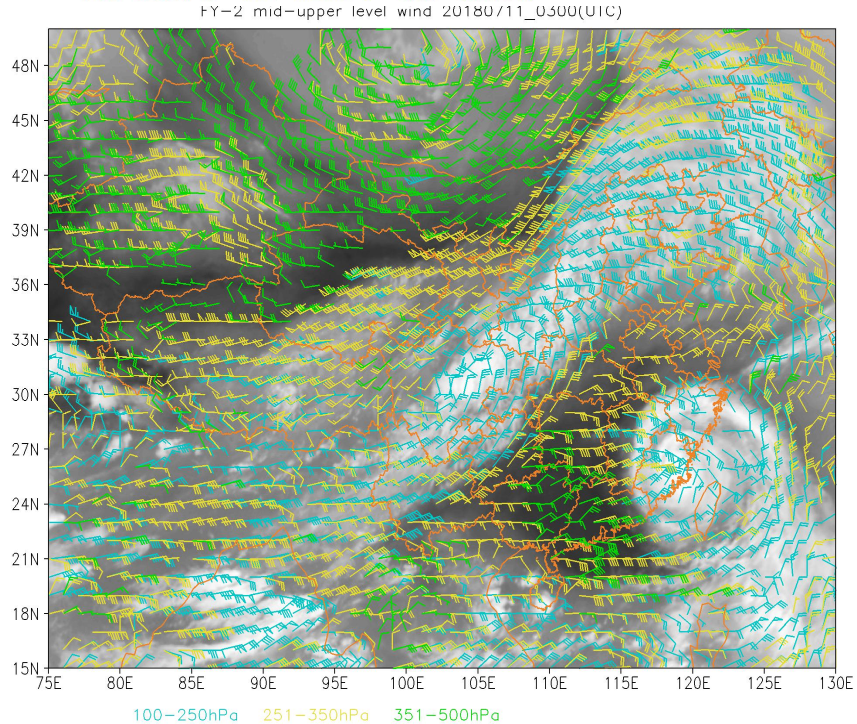
outflow

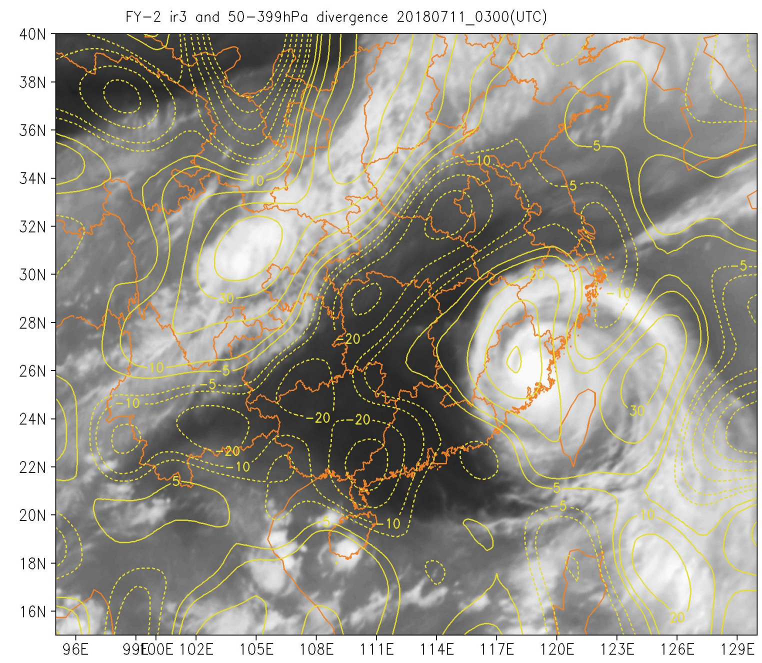


The upper –layer wind and divergence of Typhoon "Maria"

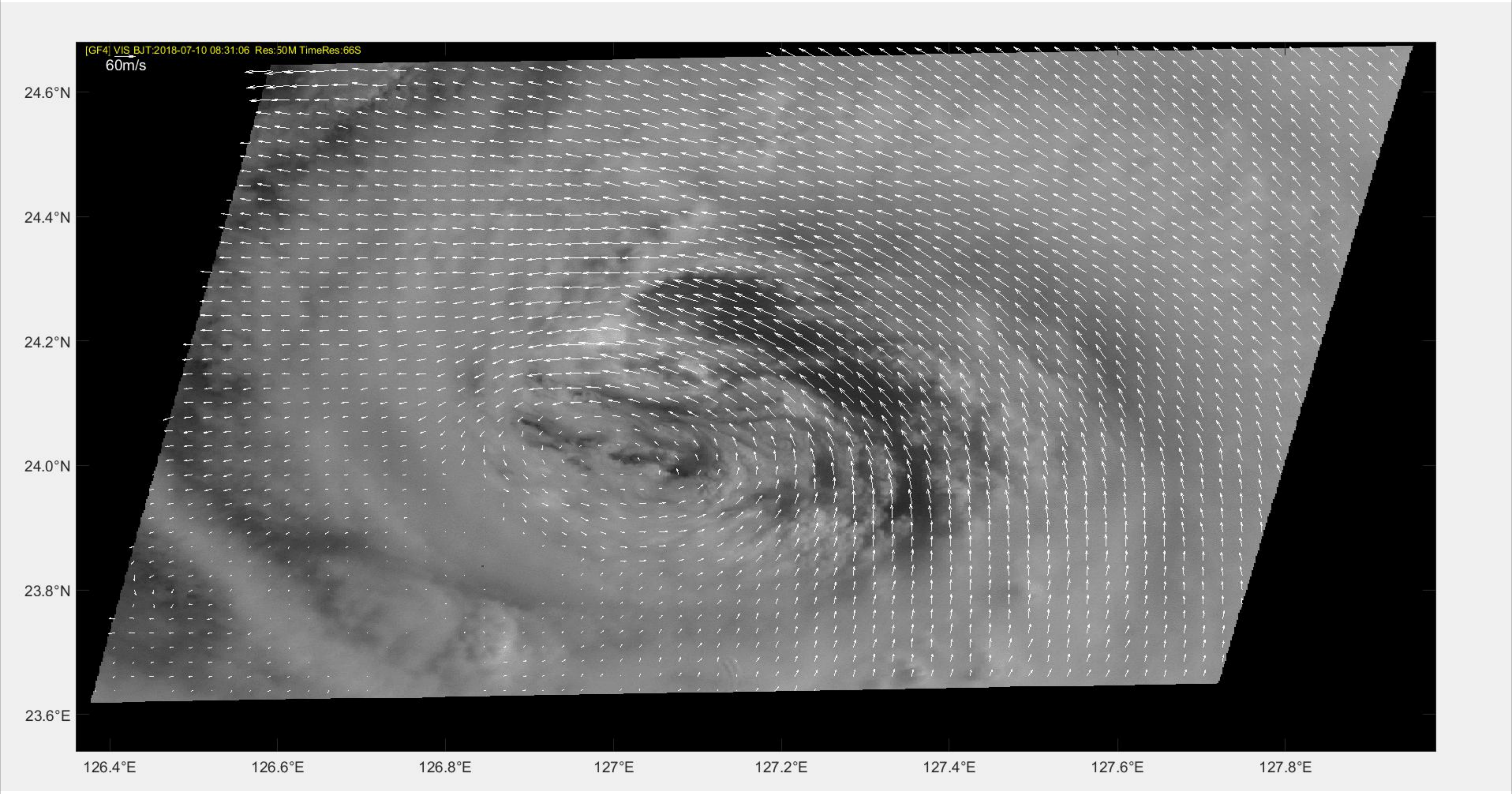








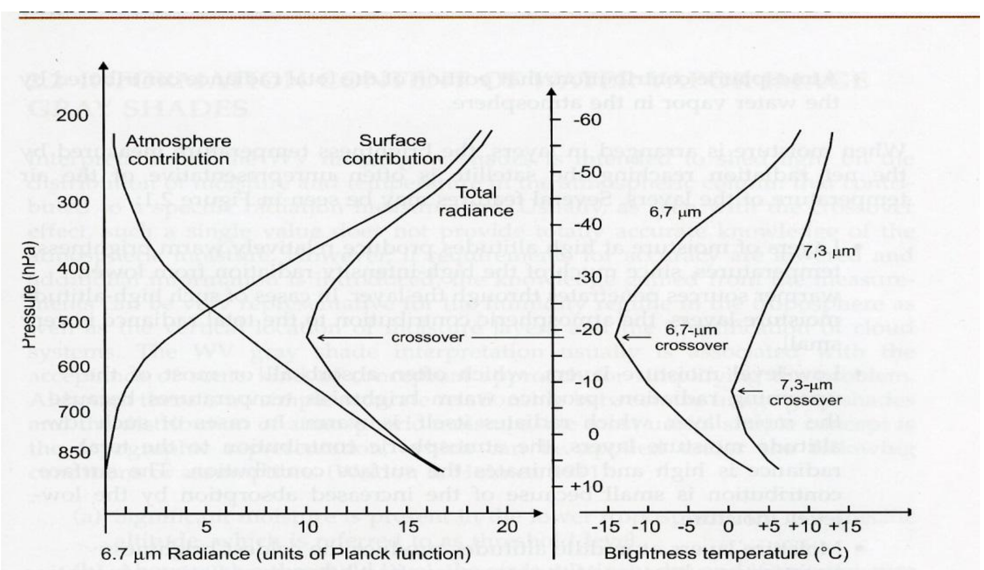
Mesoscale wind field of typhoon center retrieved from GF4 data



Water vapor image and Tropopause folding detection

Radiation contribute by the surface | **Radiation contributed by the atmosphere**

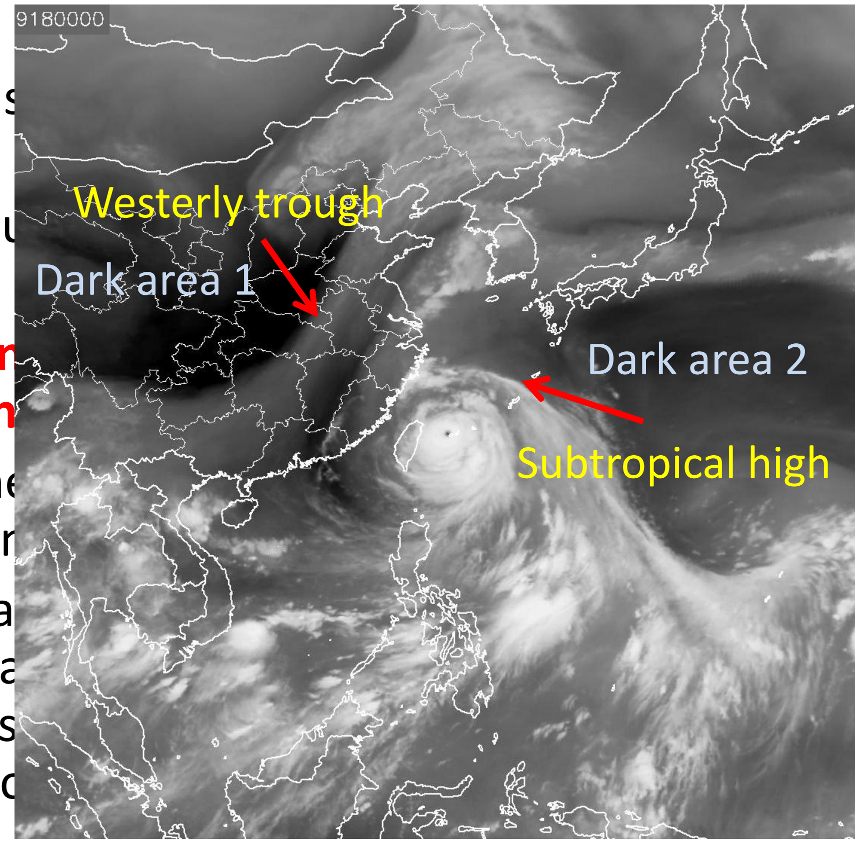
net radiation to the satellite in WV channel = **Radiation emitted by the surface** — **Radiation absorbed by water vapor** + **Radiation emitted by the water vapor**



crossover effect

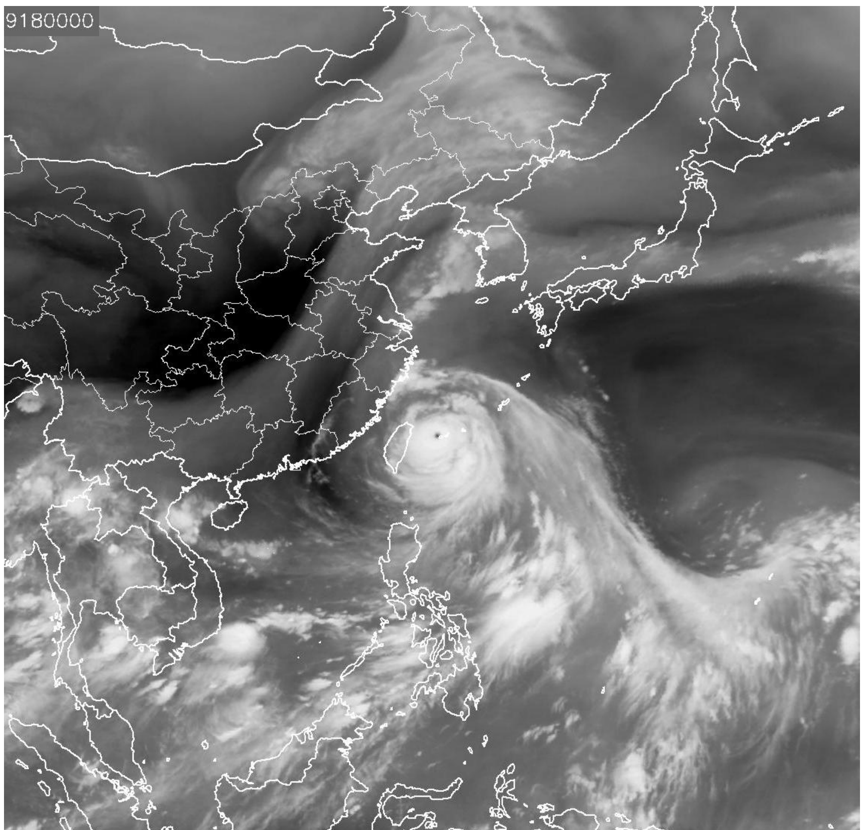
when water vapor exist at mid level, the total radiation to satellite in WV channel is the smallest, and is the whitest part shown in the image

- Water vapor image is an important tool for forecasters to analyzing TCs, as it reflects the relationship between the changes of dry and wet region and the motions of trough and ridge.
- **The subtropical high and the westerly trough** are the main factors affect the TCs motion. Because their interactions and changes can indicate the change of steering flow.
- **Dark area** can in the water vapor image s
atmosphere.
- Dark area over the ocean mostly is the su
land is westerly trough.
- **The dark area shape and its changes car
subtropical high, and further indicate th**
- changes of the dry and wet regions in the
uncover the characteristics of the motior
- It can not detect the 80% water vapor a
important to the rainfall. But the WV ima
change of gray level in WV images shows
at mid troposphere which is important tc



Example1: To the north west and make landfall

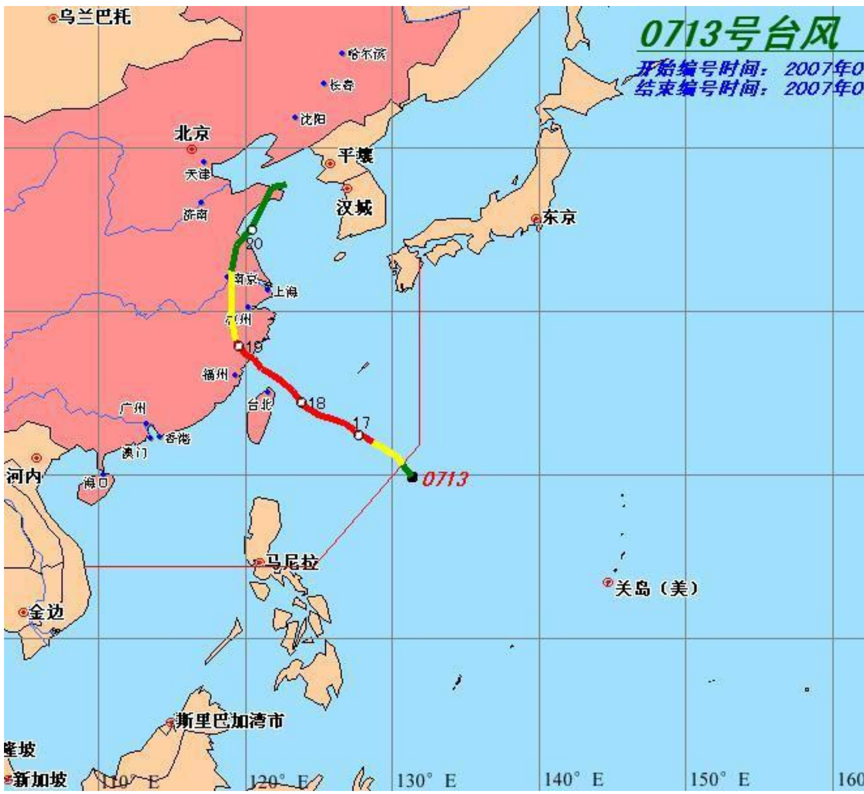
Features: The subtropical high gets darker and darker; forms **a sharp horn** at the Westside and further stretches to the west. At the same time, TC is on its southwest.

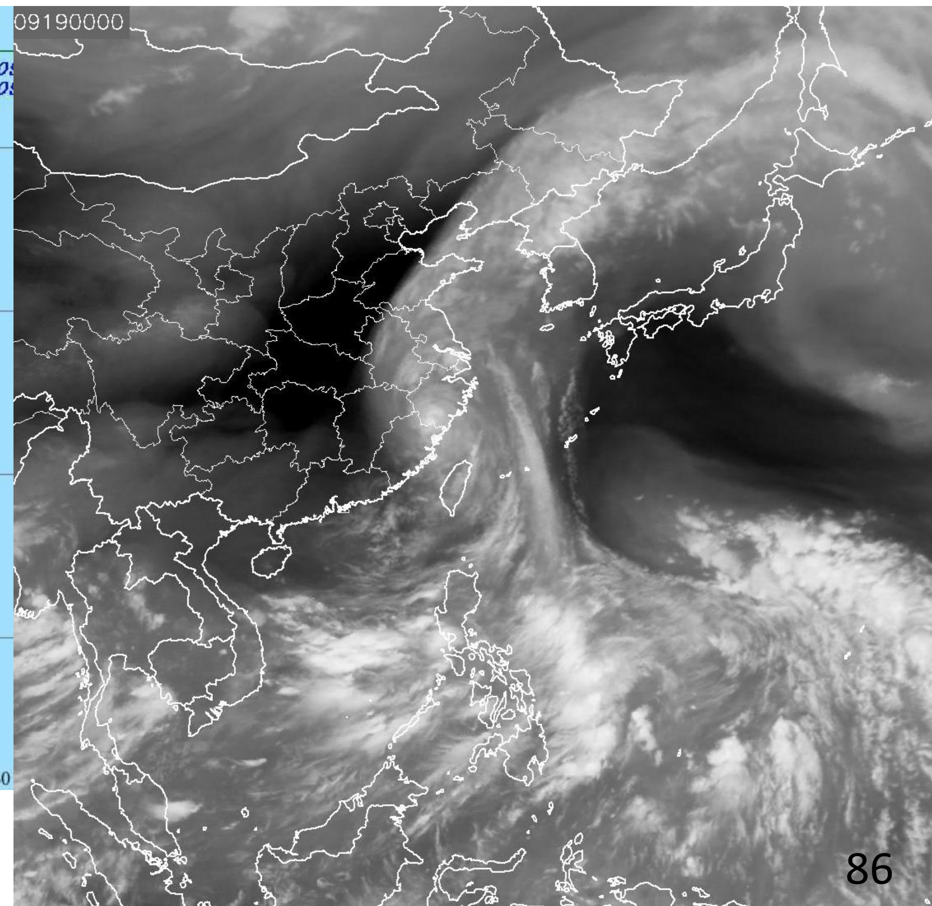


The track for typhoon 0608

Example2: To the north west , make landfall and turn to other direction

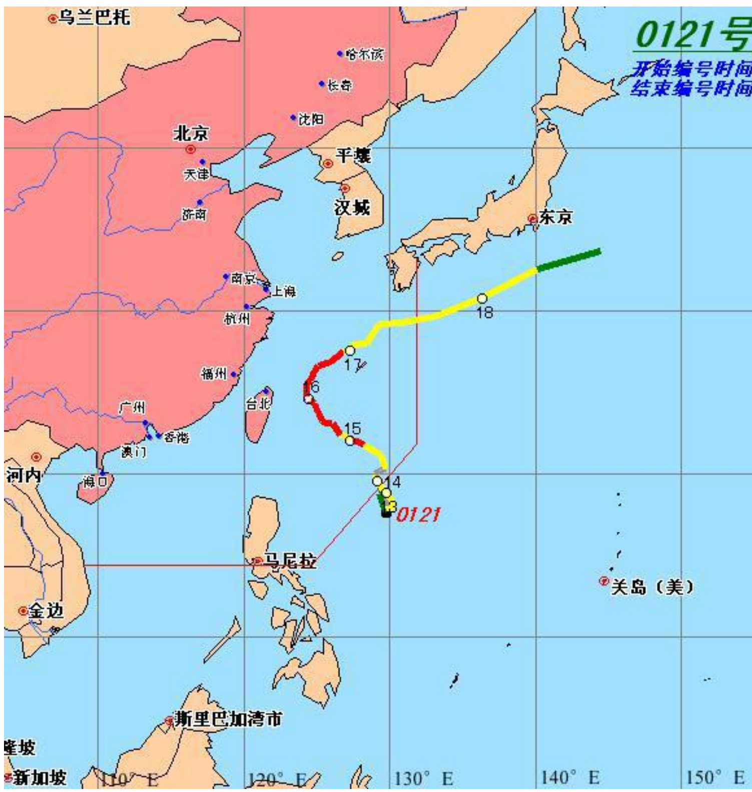
Features: The subtropical high stretches to the west like **a obtuse angle horn**. At the same time, TC is on its southwest.

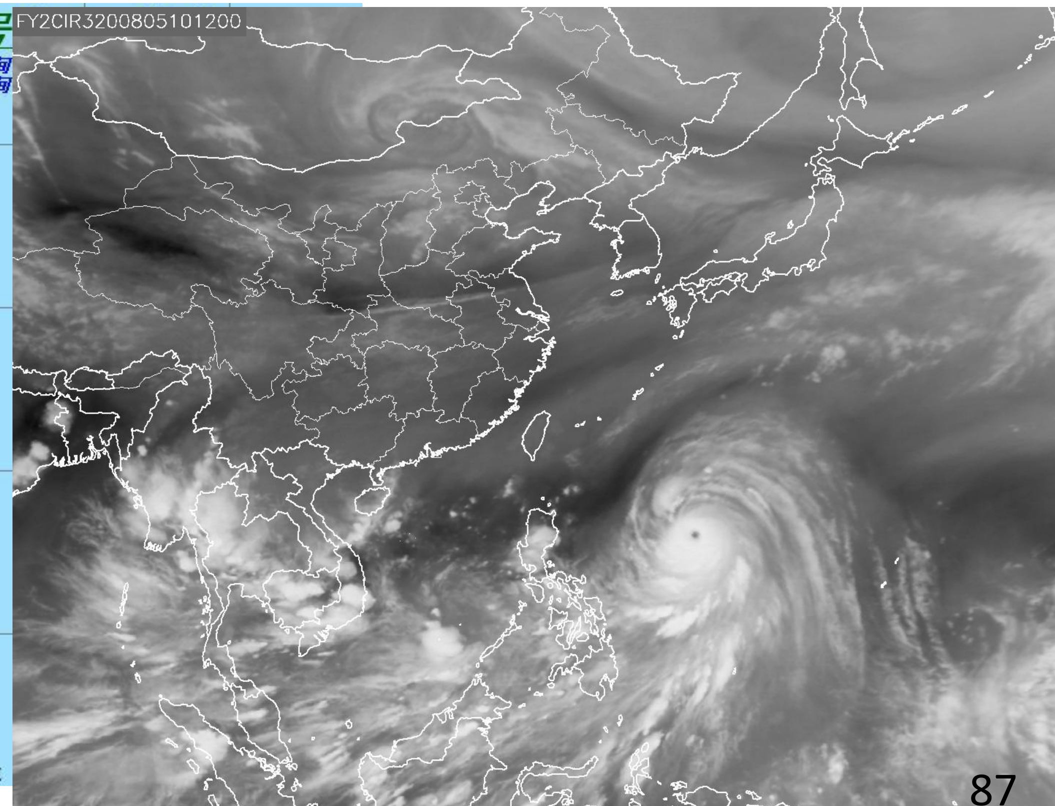




Example3: To the north west , and turn to other direction when near the shore

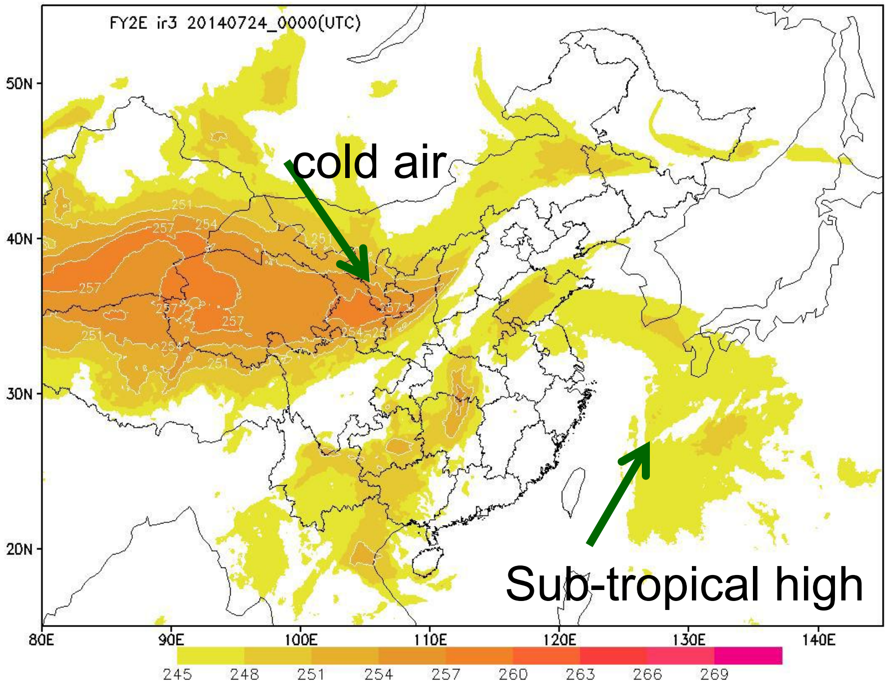
Features: The location of the subtropical high is more on the east. The boundary of the subtropical high is obscure and less dark. The boundary of the mainland is clearer. At the same time, TC is on its southwest.

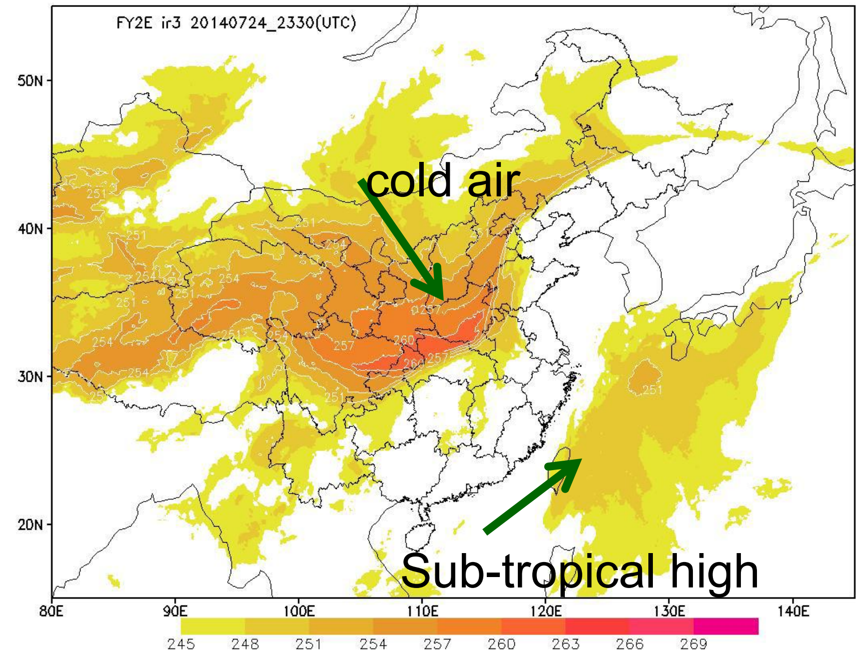




In order to show the usefull information on WV images. We developed the product of dark area

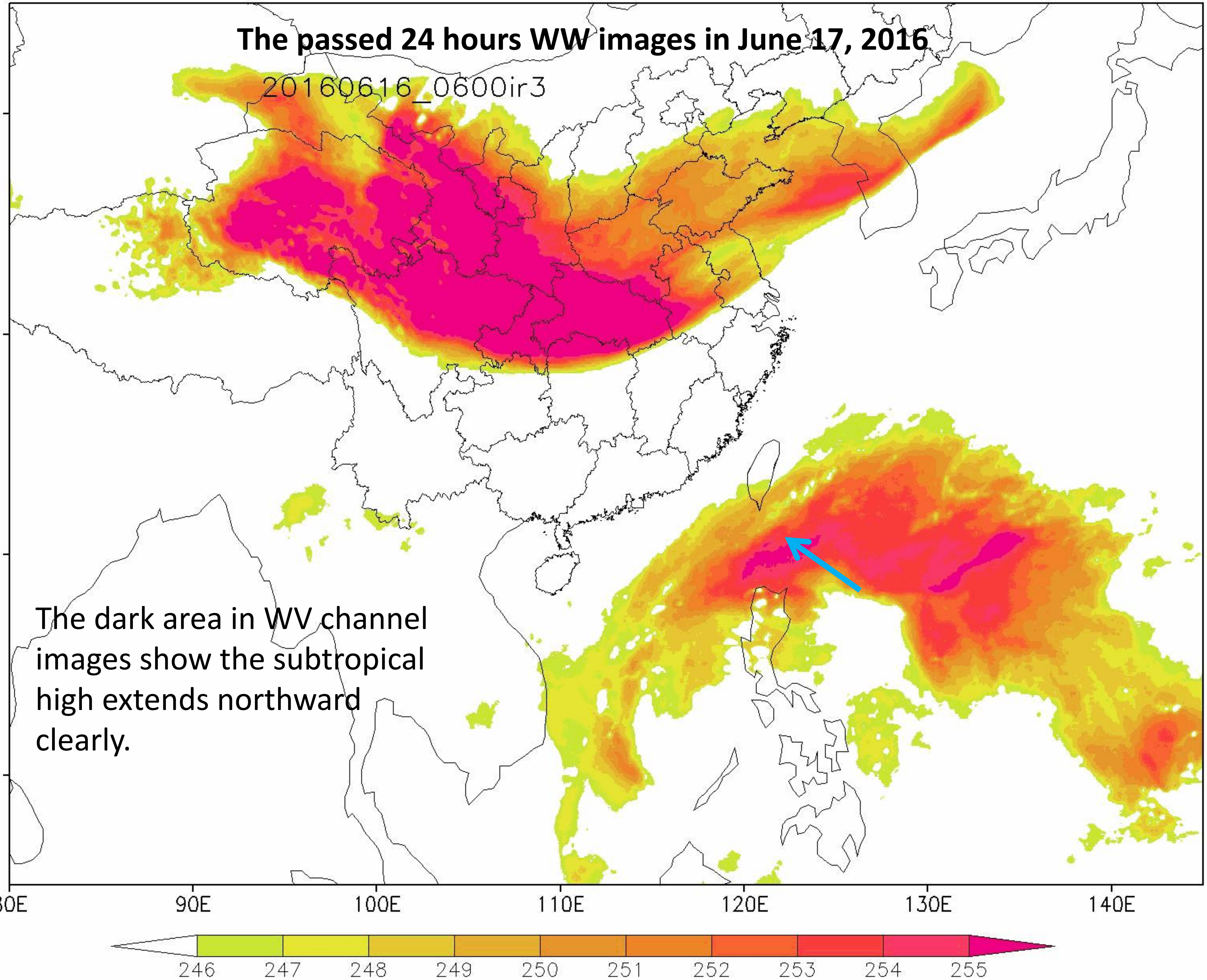
IR3 image dark area





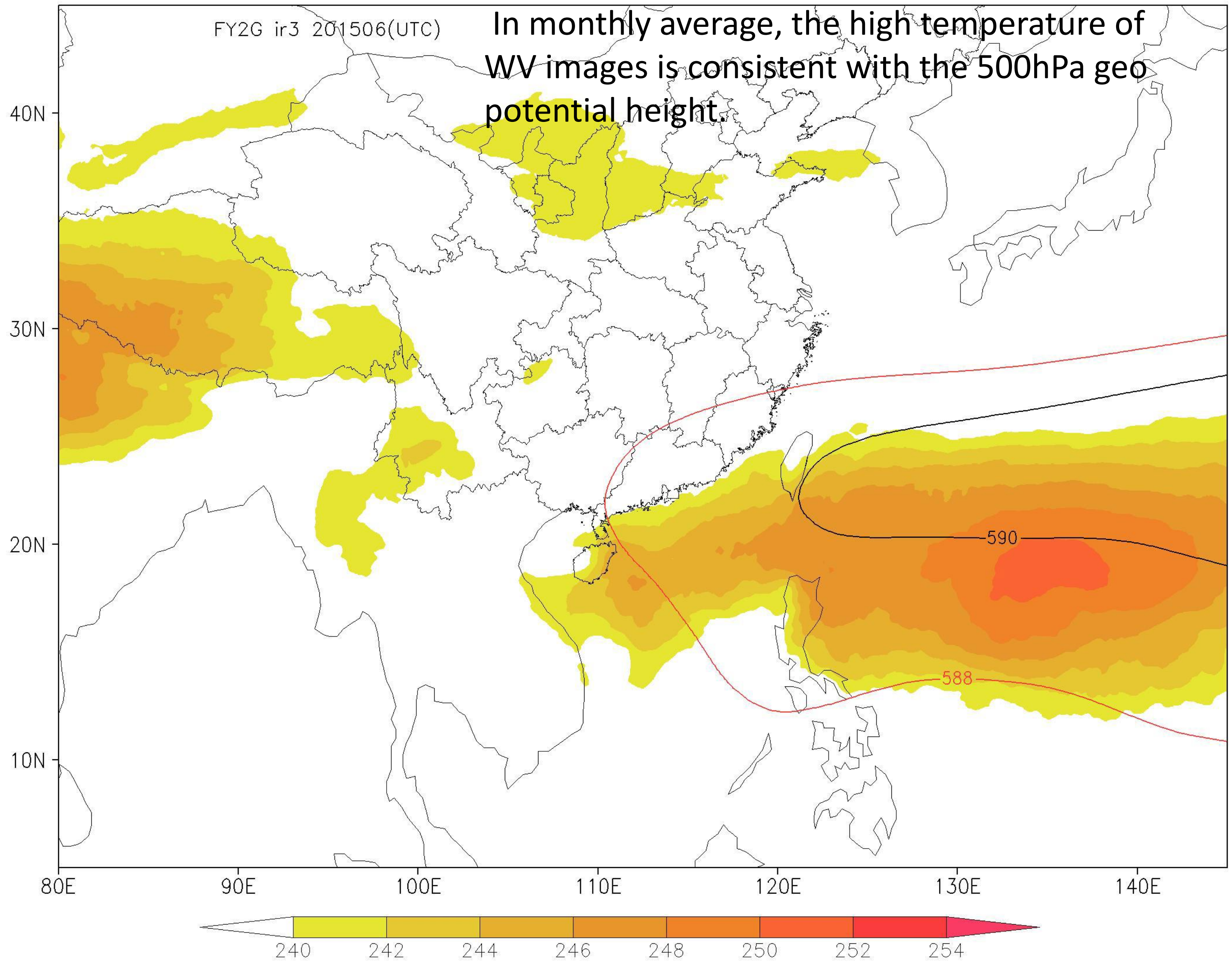
Cold air and sub-tropical high are all important to heavy rainfall, tropical cyclone and other weather system in summer.

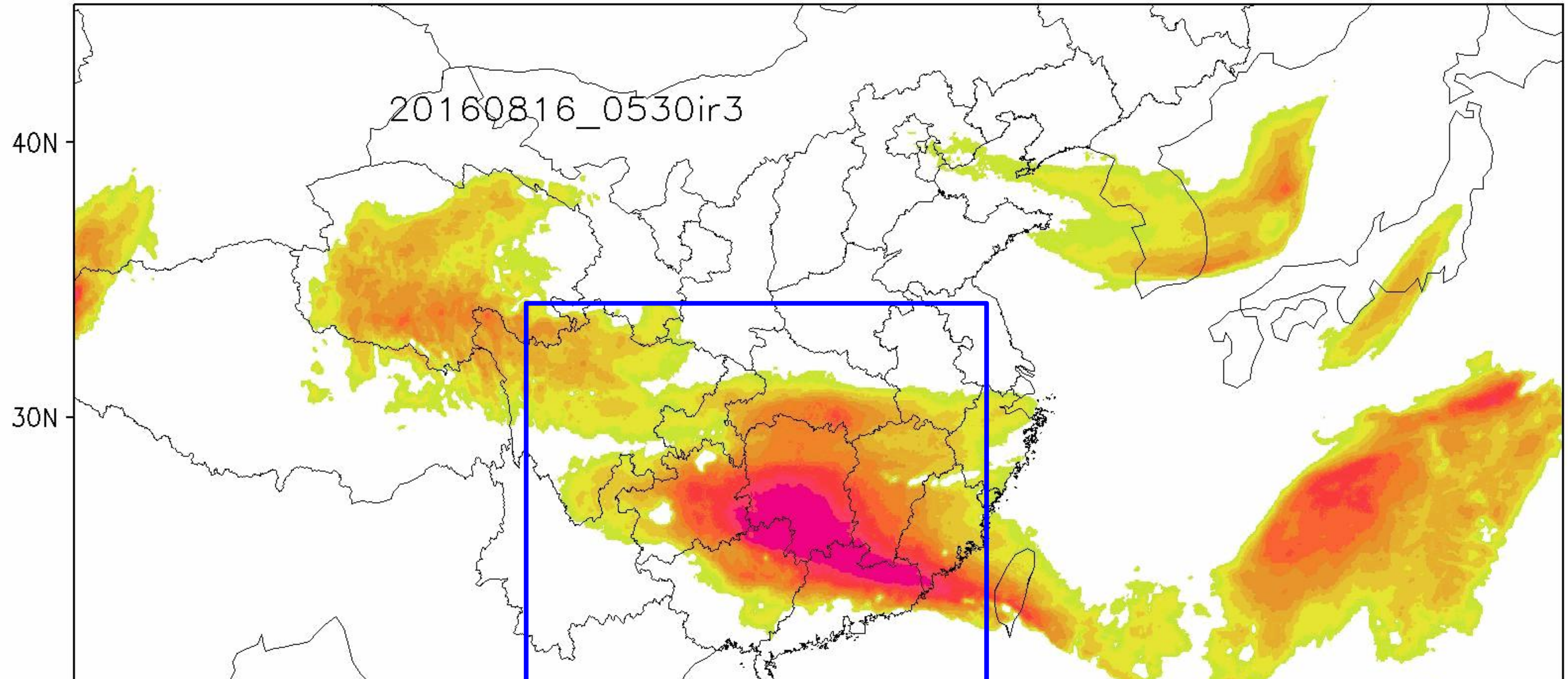
The passed 24 hours WW images in June 17, 2016

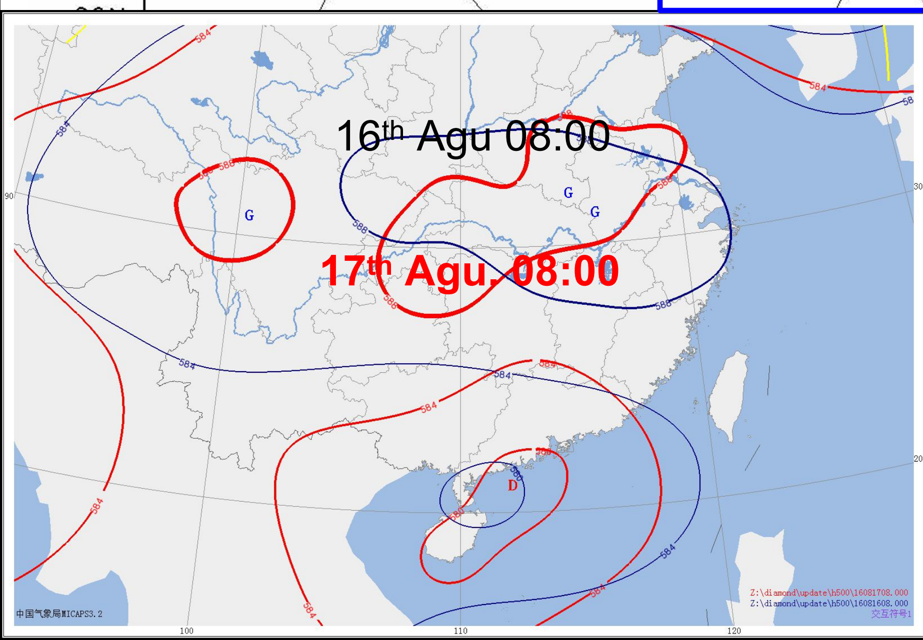


The dark area in WV channel images show the subtropical high extends northward clearly.

In monthly average, the high temperature of WV images is consistent with the 500hPa geo potential height.

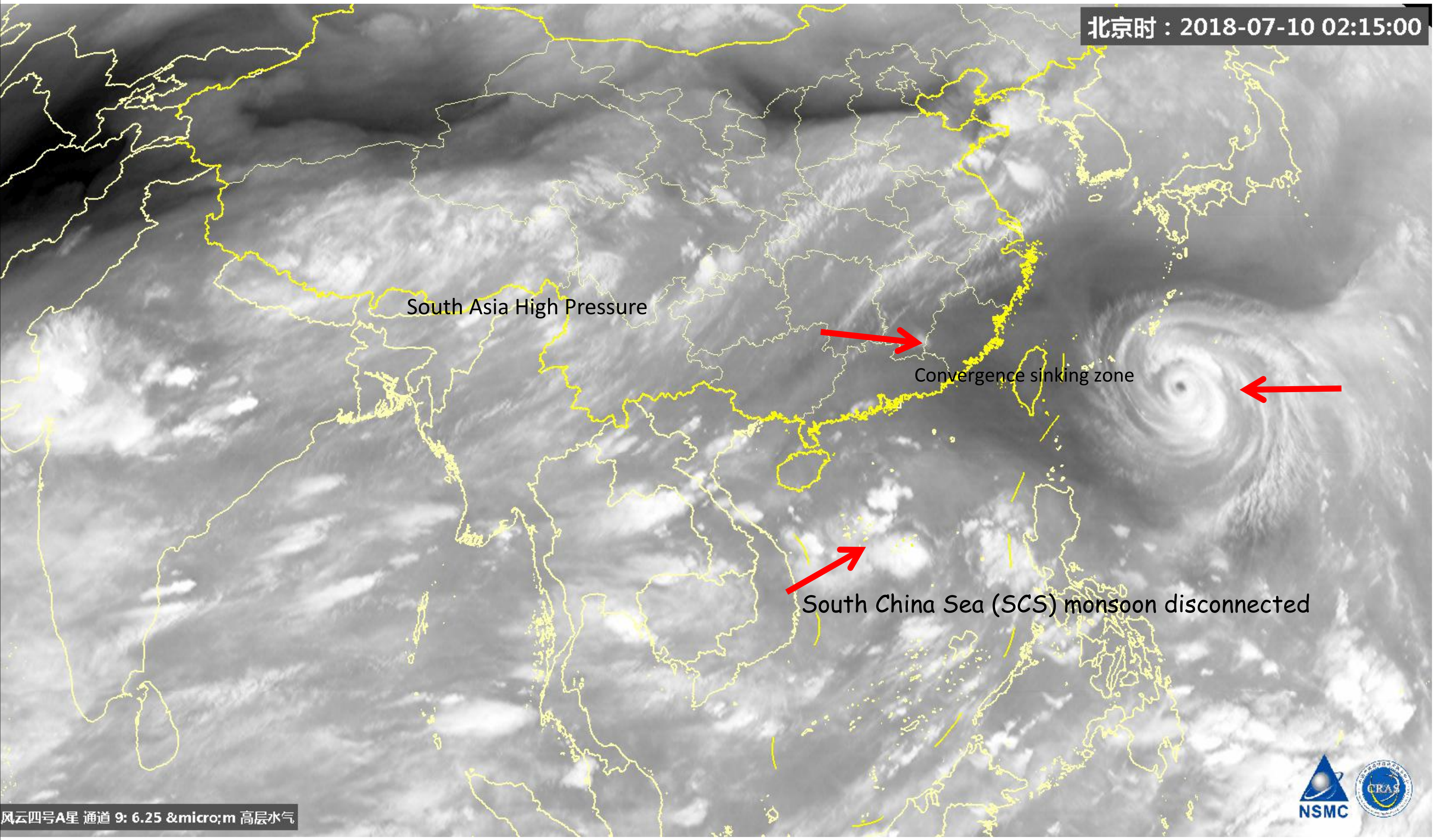




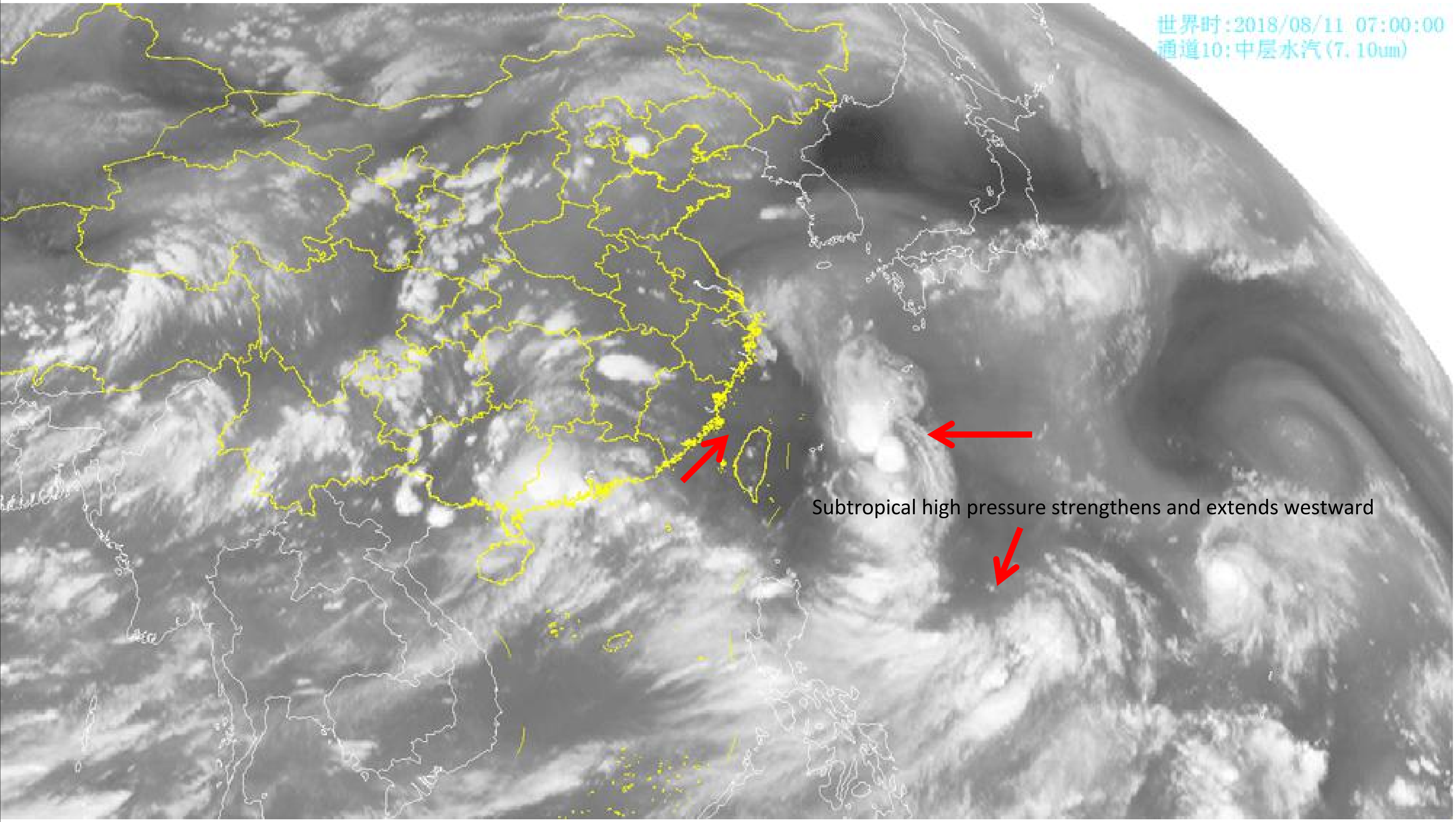


The WV images showed that the subtropical high developing southwest

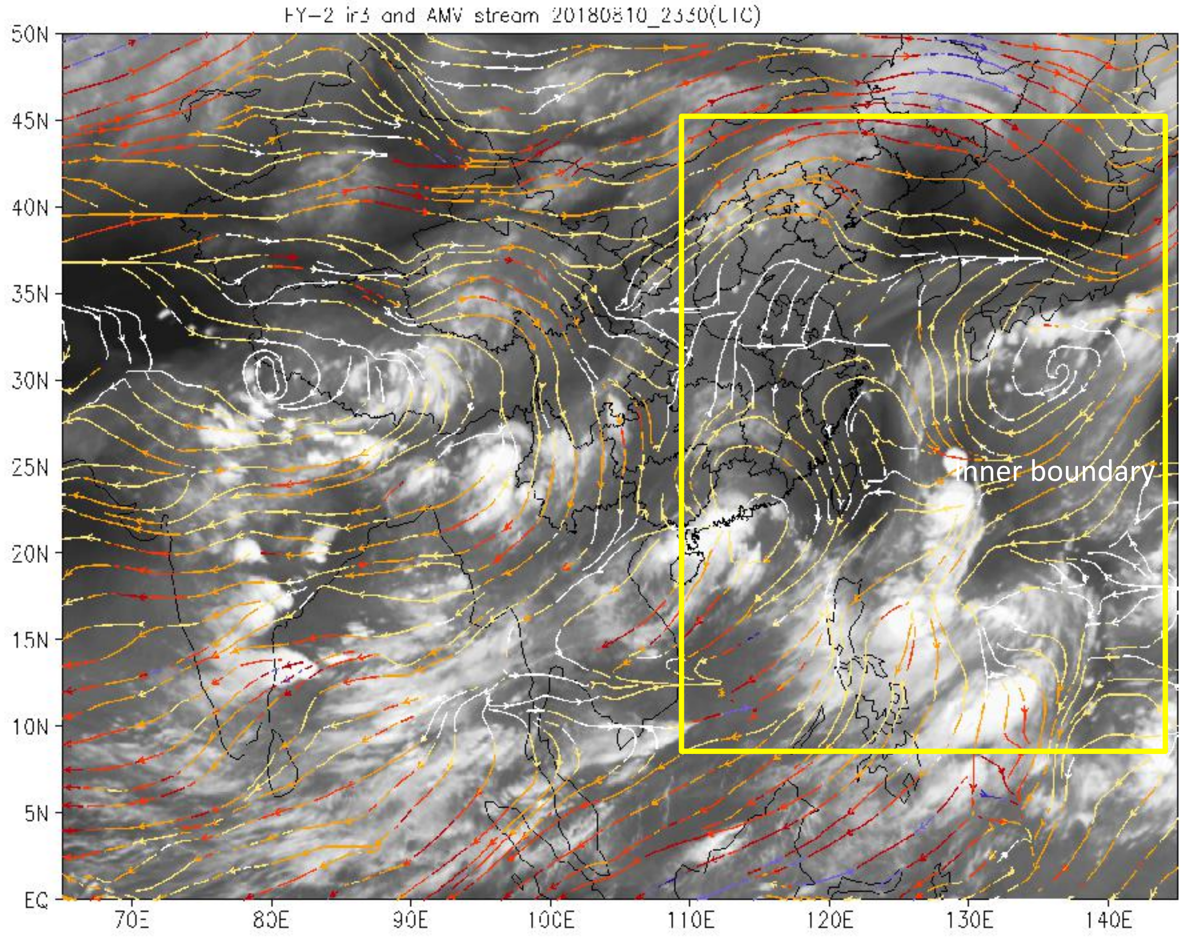
FY-4A Water vapor image animation of Typhoon "Maria"
14:00 9/7 – 14:00 10/7



FY-4A Water vapor image animation of Tropical Storm Yagi
15:00 11/08 – 14:00 12/08



High-level flow field animation from FY-4 AMV
11:30 11/08 – 13:30 12/08



The dark area on the east side of “Yagi” developed into a clear inner boundary, and the inner boundary of the water vapor rapidly moved westward. The high-altitude cold vortex on the south side of the inner boundary is conducive to the development of the low-value system on the southeast side.

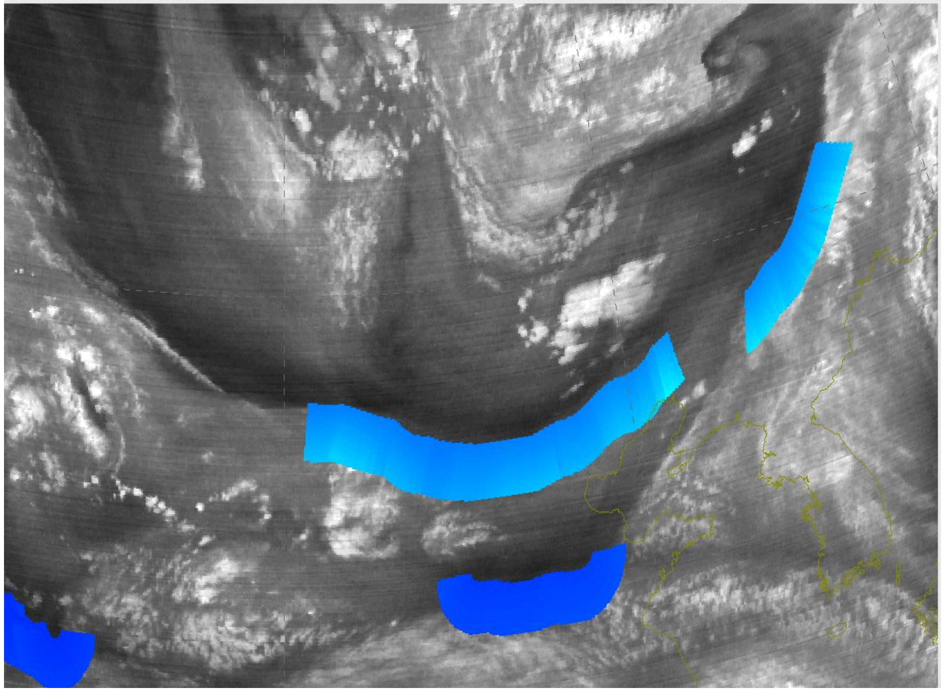
FY-4 Tropopause folding detection

- **Inputs**: a) FY-4 Channel 9 (6.25μm) brightness temperature;

  b) NWP model data: temperature (T), pressure (P), potential temperature(θ) , wind (U,V)

1. Upper level averaged moisture retrieval
2. Gradient calculation and segmentation
3. Optimization and adjustments
4. Tropopause folding depth determination
5. Dangerous flight direction calculation

FY-4 Tropopause folding detection flow

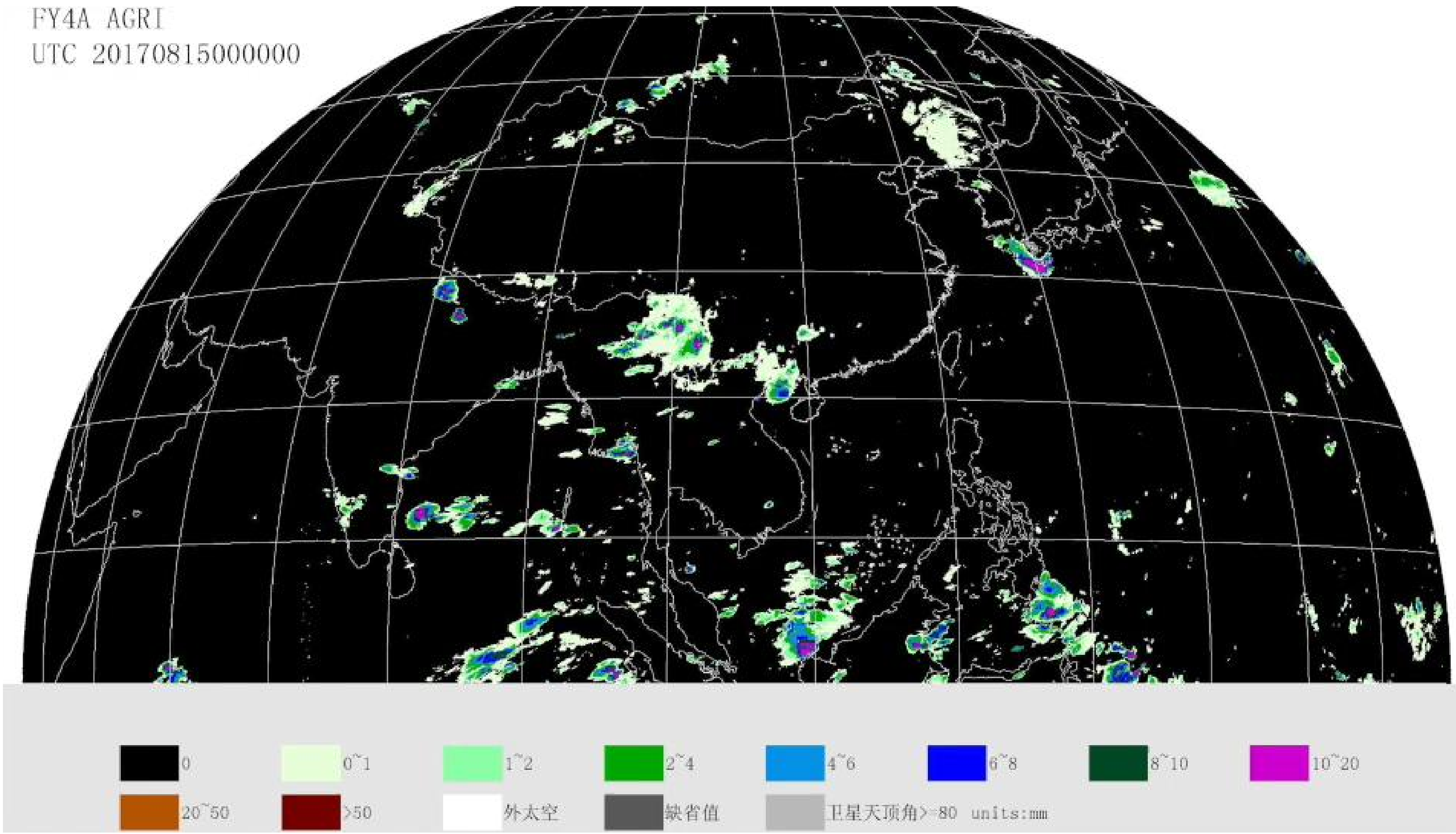


2017-06-19 04UTC-10UTC

A helpful information for turbulence detecting

FY-4 Quantitative Precipitation(FQPE)

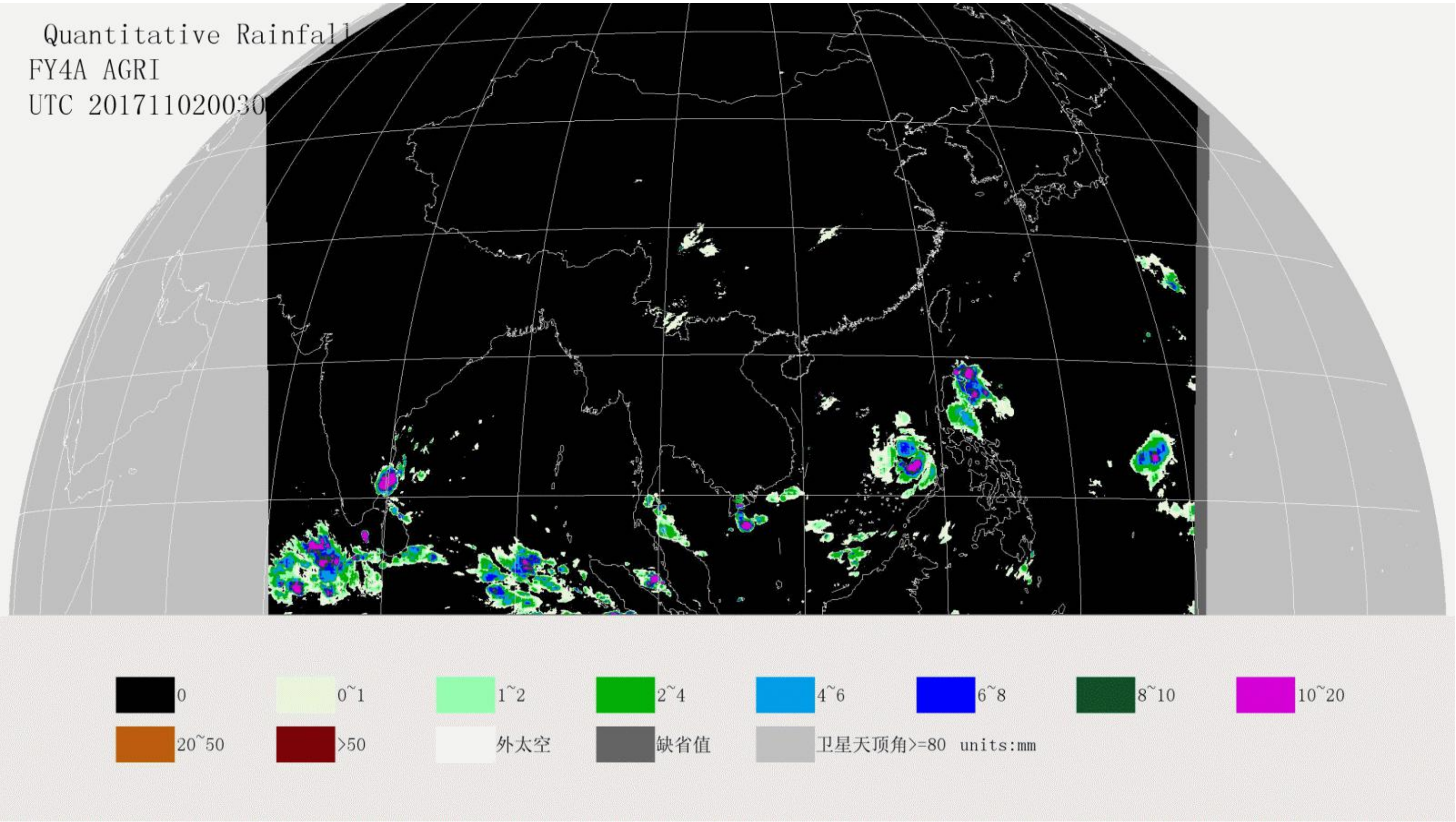
- FY-4A Quantitative Precipitation Product (FQPP) combines VIS/IR and passive microwave



QPE from FY-4A global observation mode (~15min)

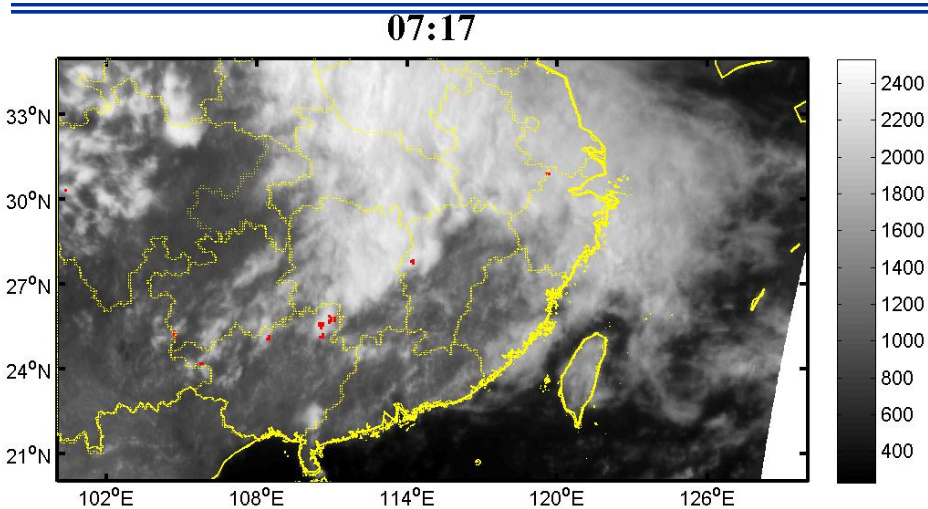
FY-4 Quantitative Precipitation(FQPE)

- FY-4A Quantitative Precipitation Product (FQPP) combines VIS/IR and passive microwave

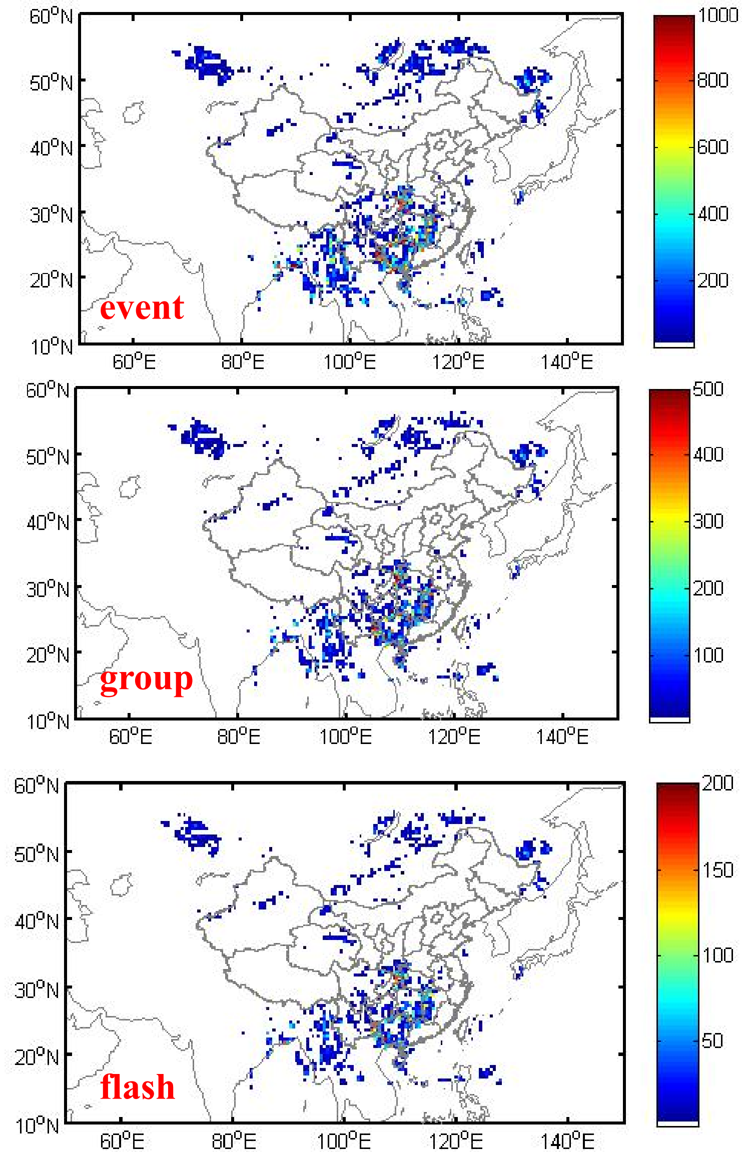


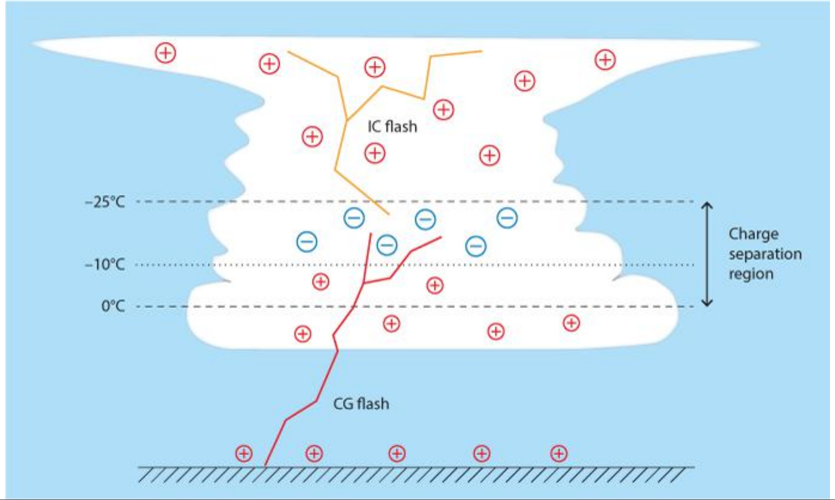
QPE from FY-4A regional observation mode (~5min)

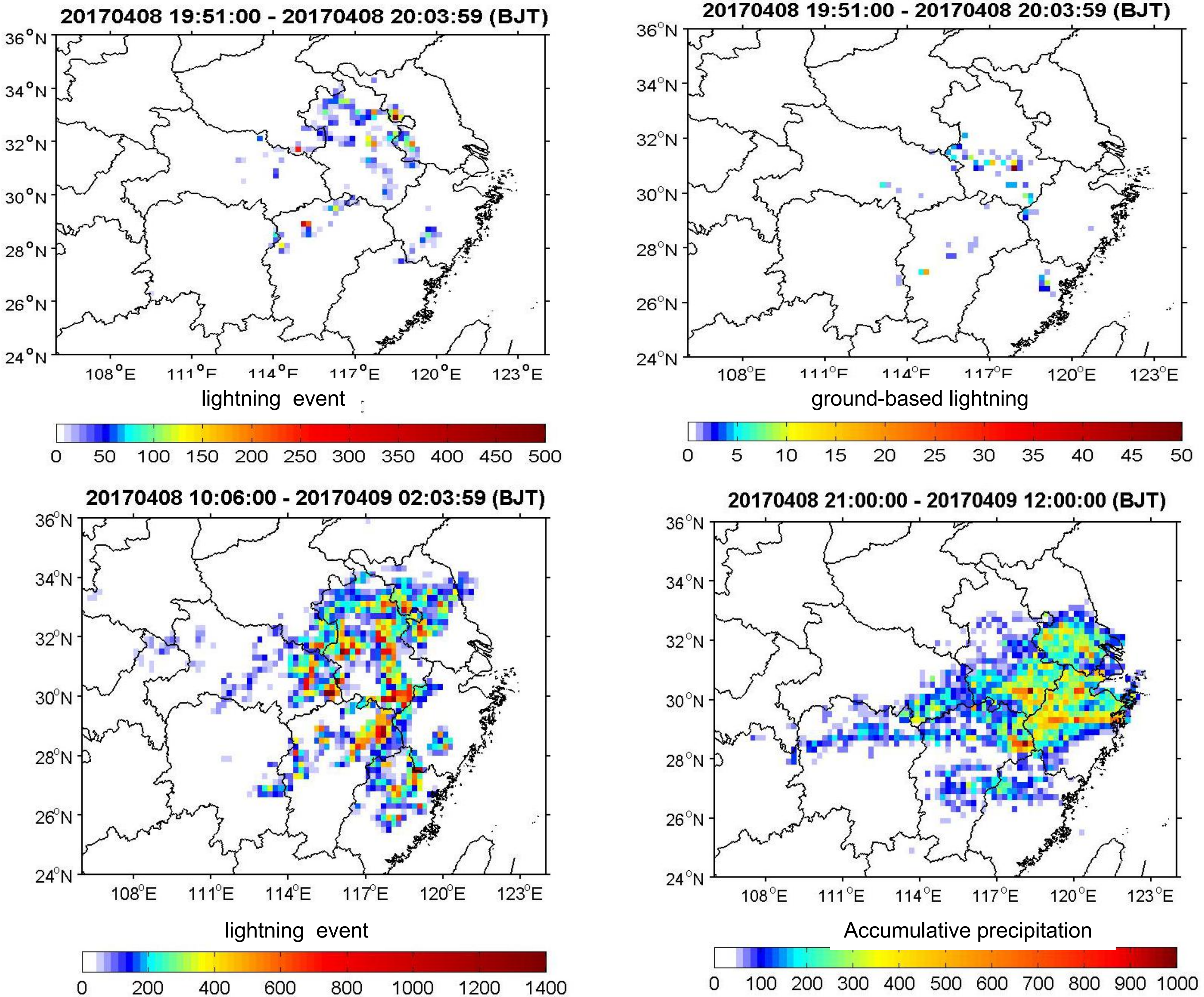
Lightning Event detected from FY-4A LMI



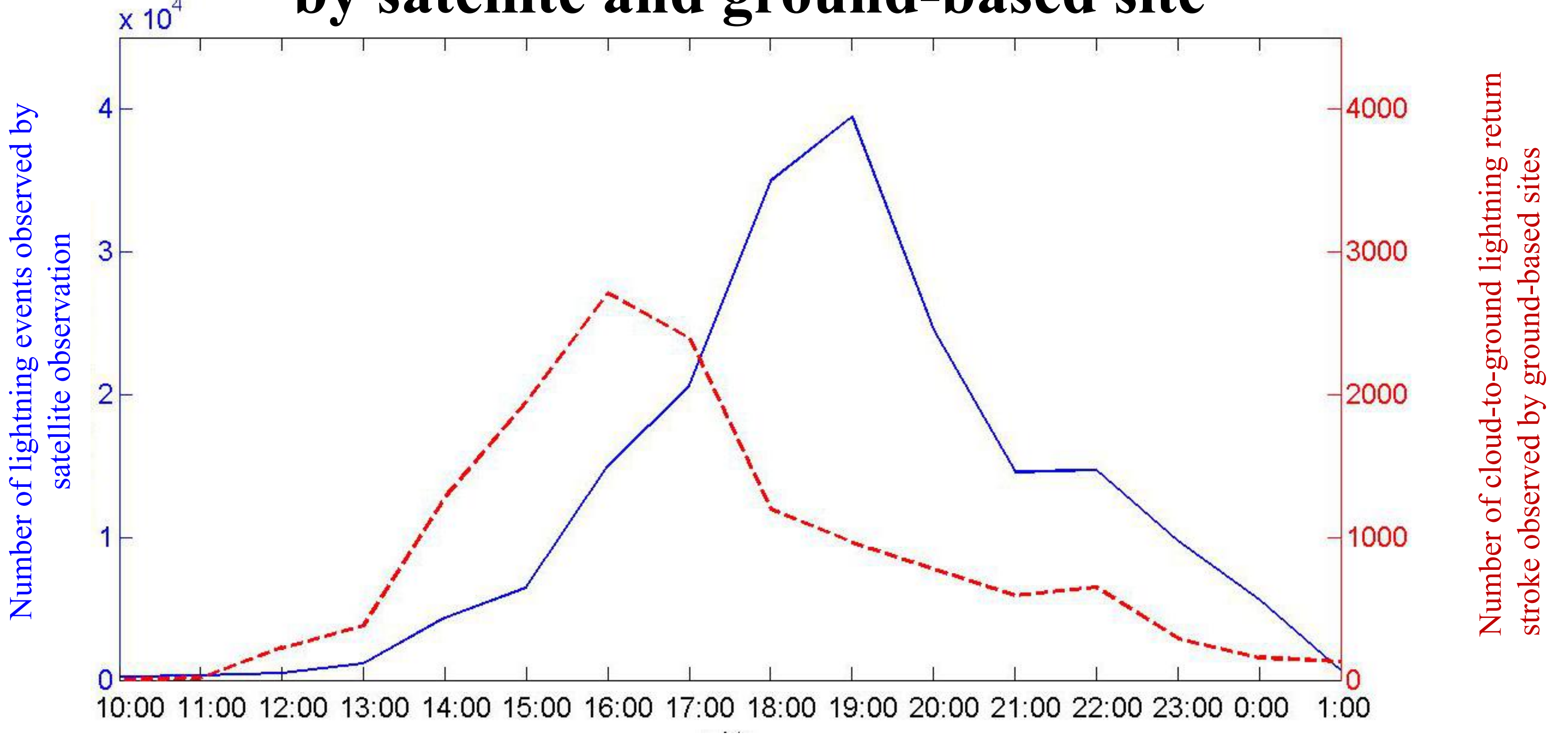
LMI lightning events about 3 hours, is displayed over the LMI background image in June 5, 2017. Red color indicates lightning events. The brightest storm system is located in the south of the Yangtze River.






20170408 19:51:00 - 20170408 20:03:59 (BJT)
36°N
34°N
32°N
30°N
28°N
26°N
24°N
108°E
111°E
114°E
117°E
120°E
123°E
lightning event
0 50 100 150 200 250 300 350 400 450 500
20170408 19:51:00 - 20170408 20:03:59 (BJT)
36°N
34°N
32°N
30°N
28°N
26°N
24°N
108°E
111°E
114°E
117°E
120°E
123°E
ground-based lightning
0 5 10 15 20 25 30 35 40 45 50
20170408 10:06:00 - 20170409 02:03:59 (BJT)
36°N
34°N
32°N
30°N
28°N
26°N
24°N
108°E
111°E
114°E
117°E
120°E
123°E
lightning event
0 200 400 600 800 1000 1200 1400
20170408 21:00:00 - 20170409 12:00:00 (BJT)
36°N
34°N
32°N
30°N
28°N
26°N
24°N
108°E
111°E
114°E
117°E
120°E
123°E
Accumulative precipitation
0 100 200 300 400 500 600 700 800 900 1000

The hourly variation characteristics of lightning observed by satellite and ground-based site



The beginning time of lightning observed by satellite is about one hour earlier than ground-based site.

- **The satellite could observe cloud-to-cloud flash and cloud-to-ground flash, but the ground-based site could only observe cloud-to-ground flash.**
- **The cloud-to-ground flashes always occur later than the cloud-to-cloud flashes.**

The time of lightning activity peak is also earlier than that of ground-based site.

- **It fully illustrated that the proportion of cloud-to-ground flash in total flash changed over time and enlarged along with the precipitation.**

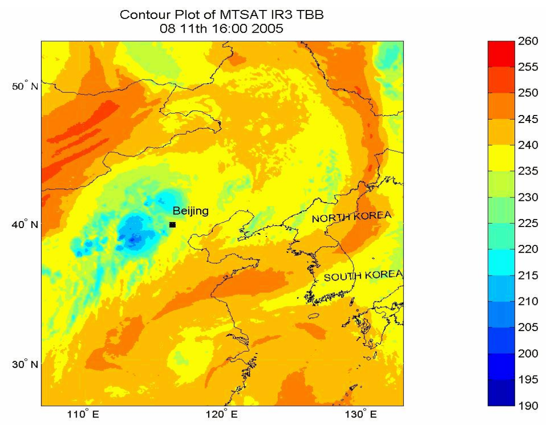
The application of Lightning Mapping Imager in Weather Services

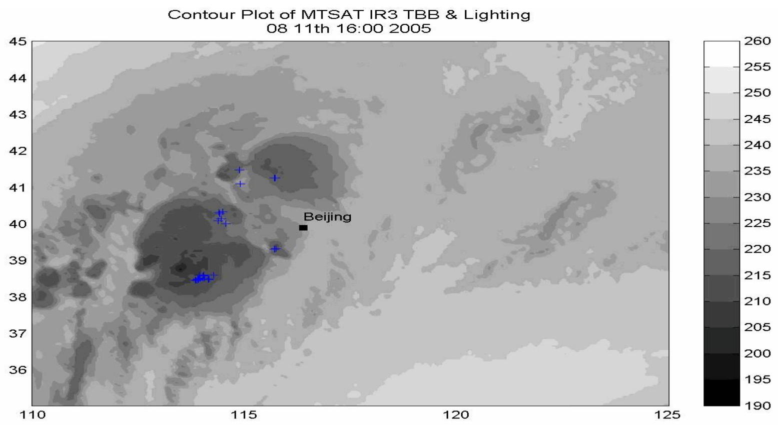
Advantages:

▪The LMI could observe mainland flashes and ocean flashes（which the coverage of radar didn’t include）

▪ The LMI could observe total flashes（include intra-cloud flash and cloud-to-ground flash）

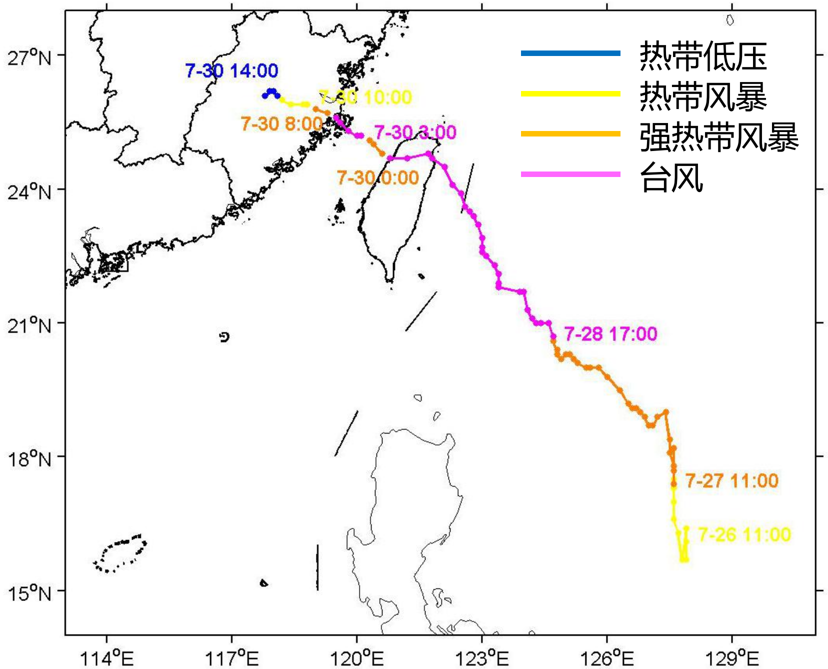
- ➢ The Lightning jump and severe weather forecasting
- ➢ The assimilation of LMI data using Nudging Method (using WRF model)
- ➢ Improve the forecasting of Typhoon intensity
- ➢ improve the precipitation estimation
- ➢ The lighting activity（climate change、atmospheric chemistry）

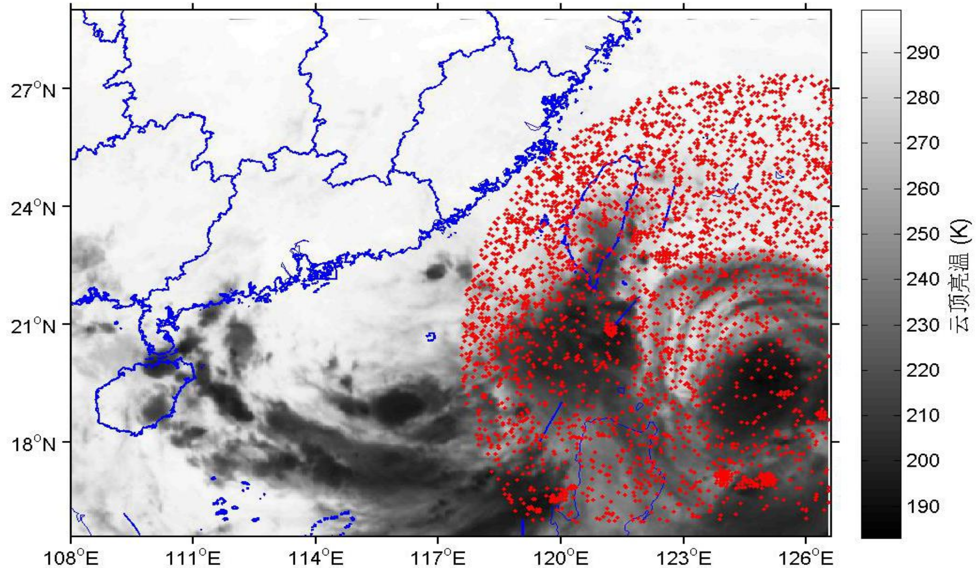




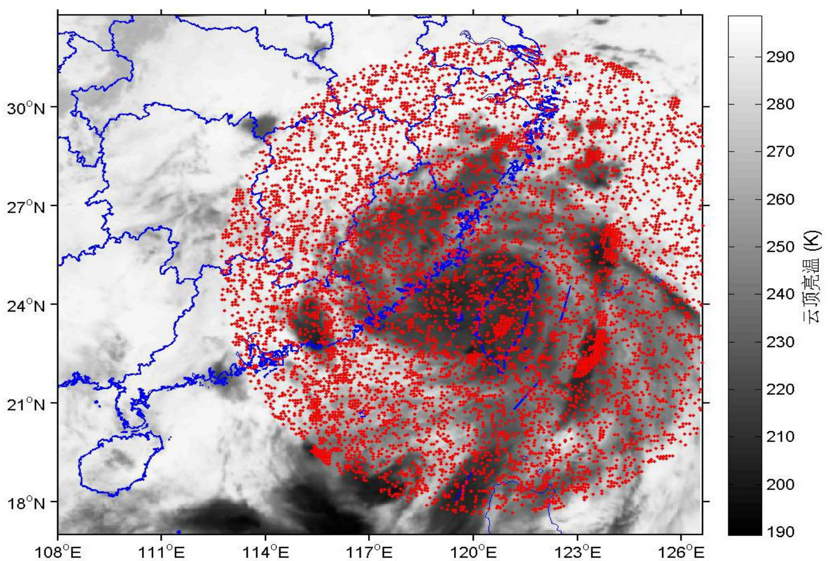
▪ **Combined with satellite images and lightning distribution maps, the variation tendencies of cloud cluster, e.g. movement and intensity, and the focused convection can be extracted directly**

Lightning distributiong in Typhoon “NESAT”





7-28 9:00



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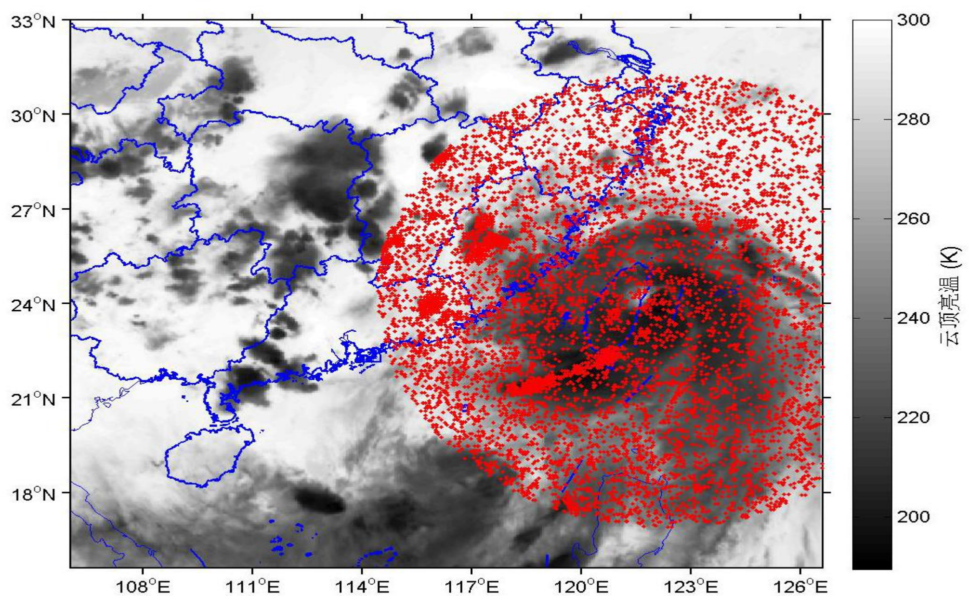

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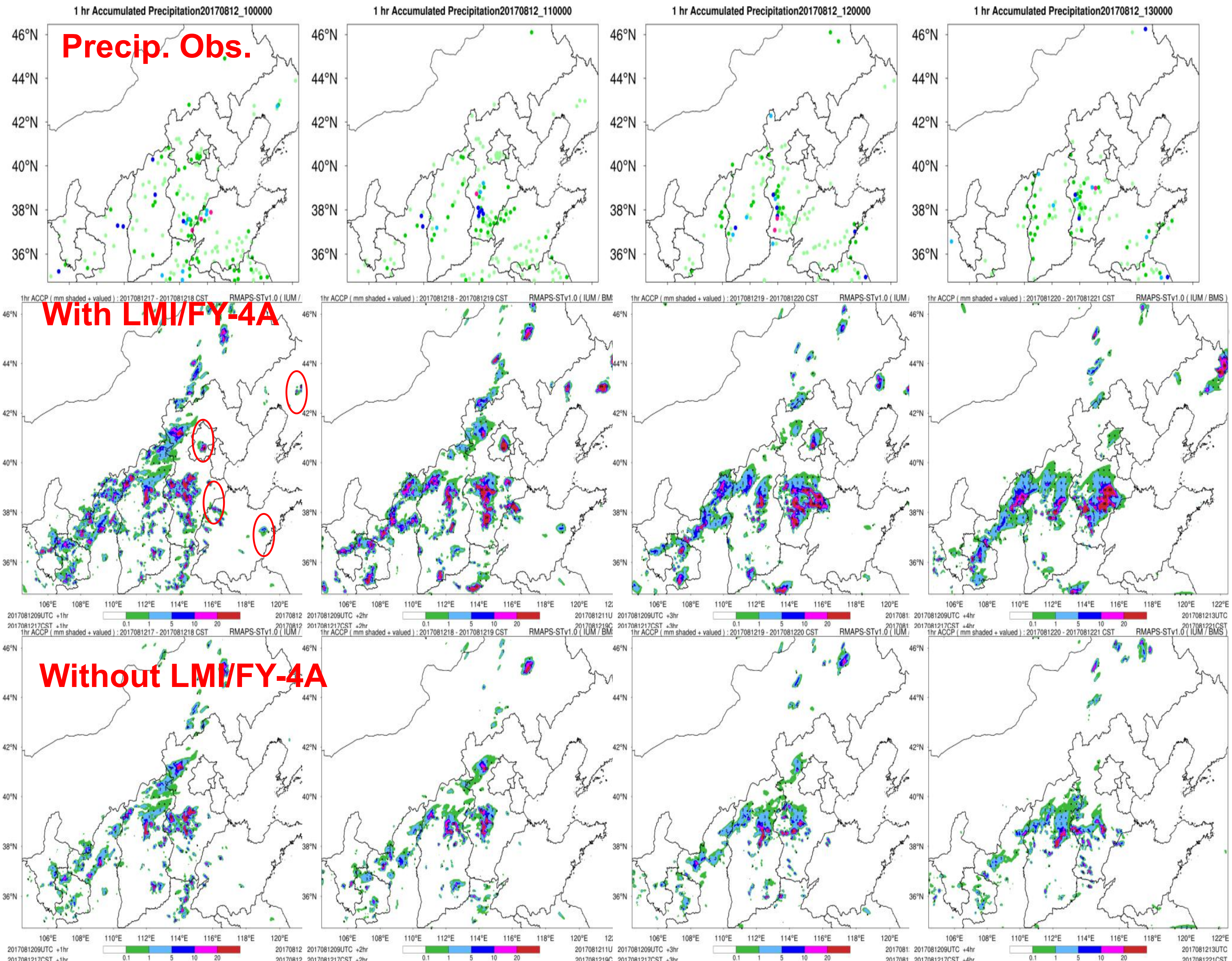
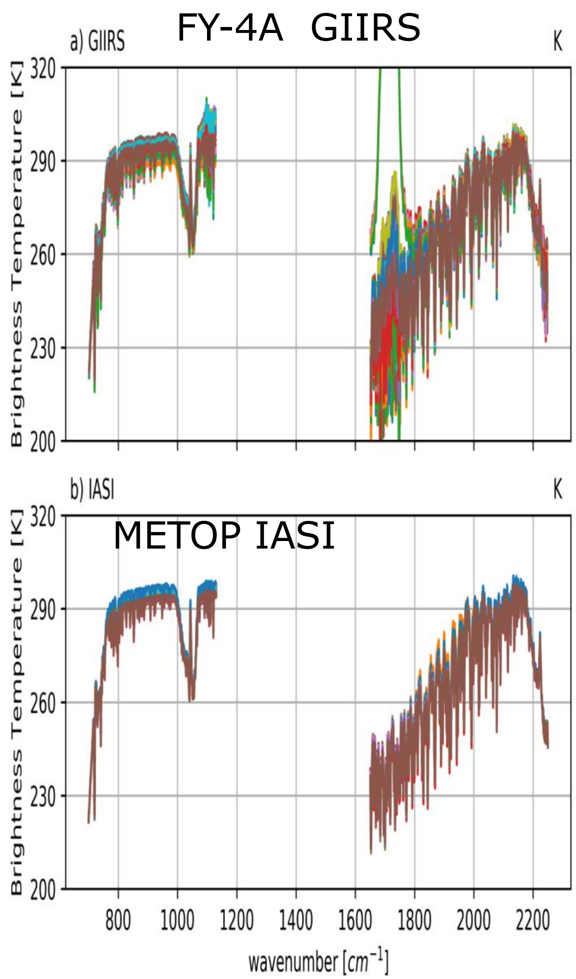
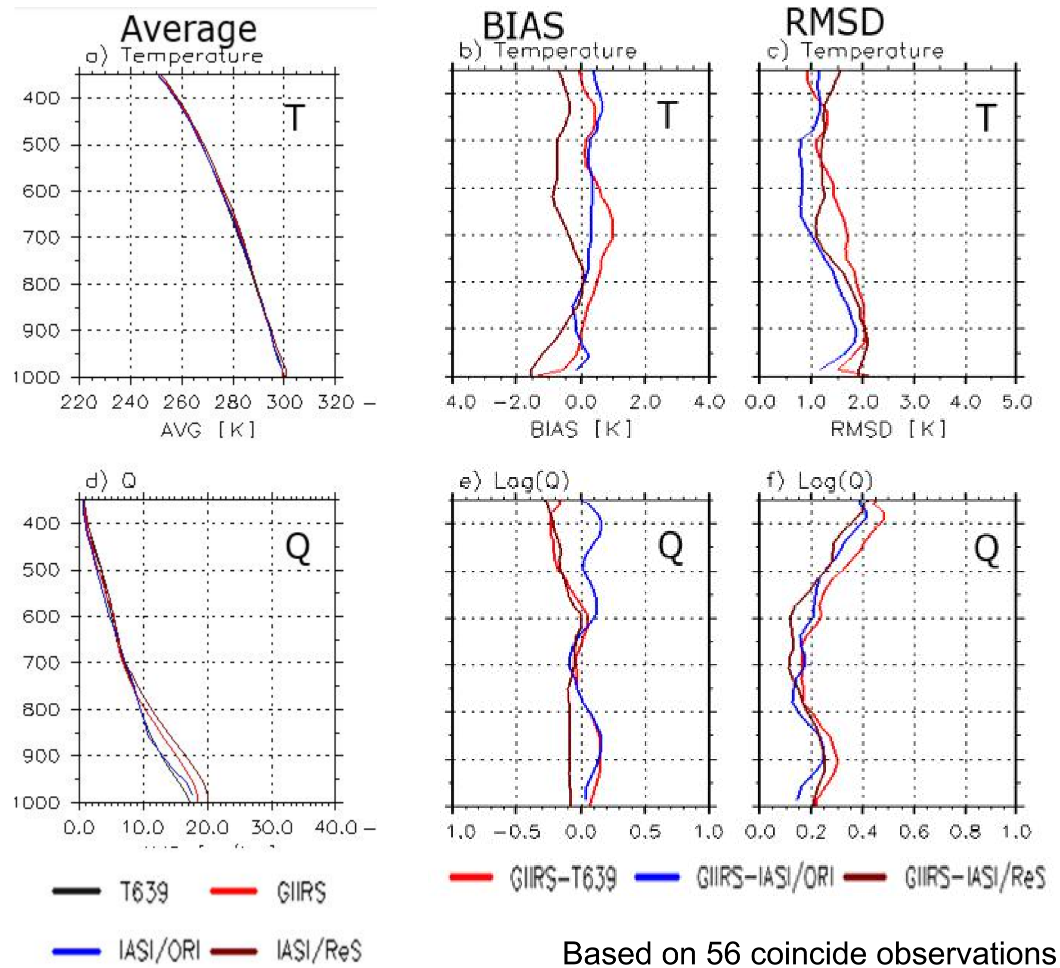

1 hr Accumulated Precipitation20170812_100000
1 hr Accumulated Precipitation20170812_110000
1 hr Accumulated Precipitation20170812_120000
1 hr Accumulated Precipitation20170812_130000
Precip. Obs.
With LMI/FY-4A
Without LMI/FY-4A
1hr ACCP (mm shaded + valued) : 2017081217 - 2017081218 CST
1hr ACCP (mm shaded + valued) : 2017081218 - 2017081219 CST
1hr ACCP (mm shaded + valued) : 2017081219 - 2017081220 CST
1hr ACCP (mm shaded + valued) : 2017081220 - 2017081221 CST
RMAPS-STv1.0 (IUM / BMS)
2017081209UTC +1hr
2017081209UTC +2hr
2017081209UTC +3hr
2017081209UTC +4hr
2017081213UTC
2017081221CST
0.1 1 5 10 20

FY-4A L2+ products from GIIRS

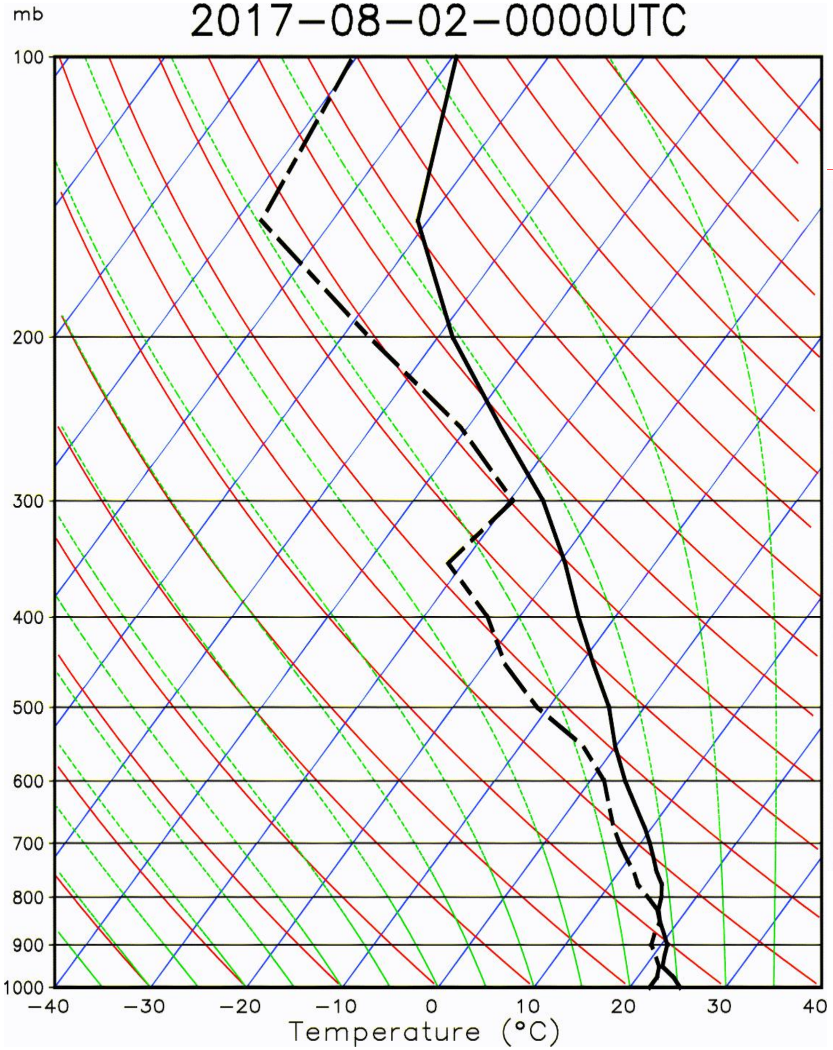
Atmospheric Temperature and Moisture profile



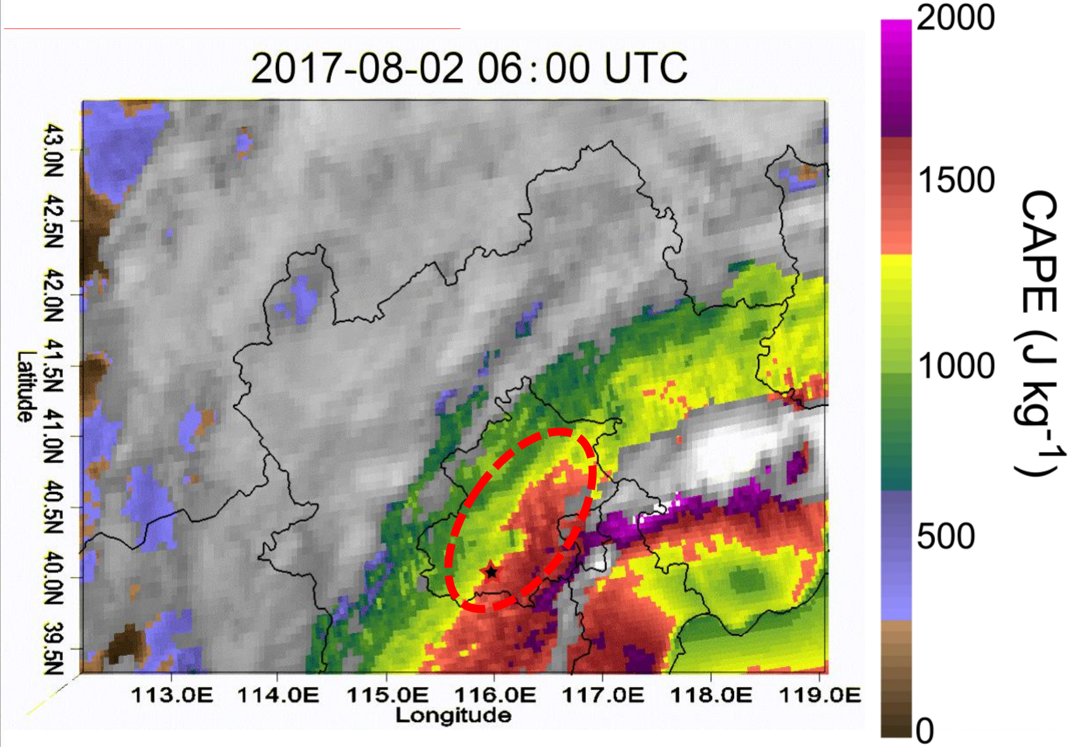


Based on 56 coincide observations of
GIIRS and IASI during Aug，2017

With LMI+AGRI+GIIRS, what can we see?

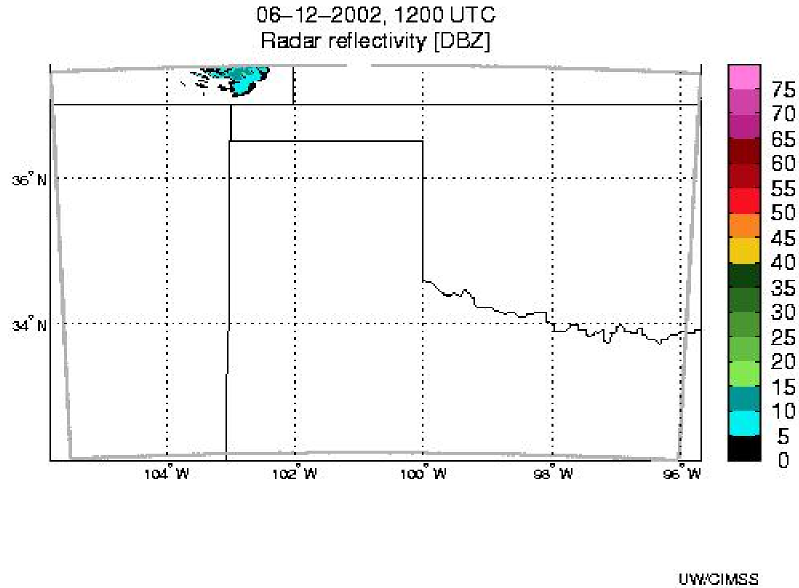


Skew T-lnP diagram over Fangshan, Beijing during 00:00 UTC-12:00 UTC (08:00-20:00 LST) 02 Aug 2017

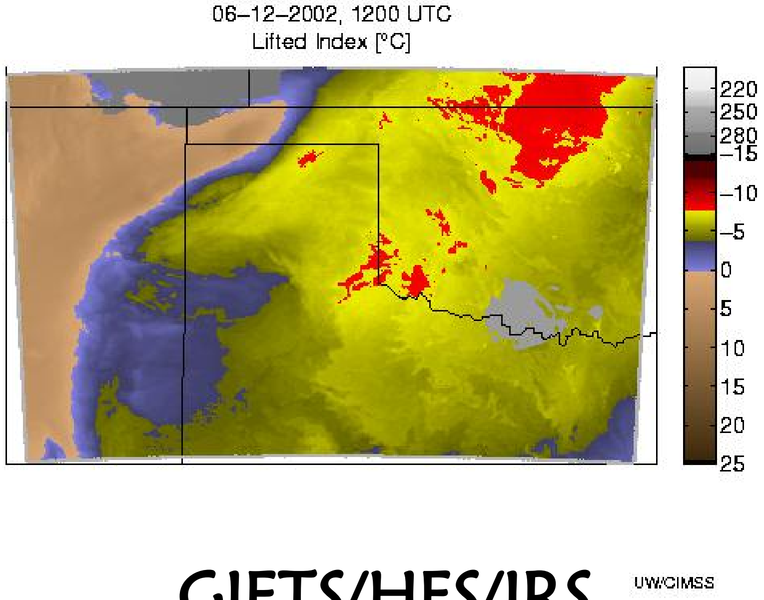


Convective Available Potential Energy (CAPE) map during 00:00 UTC-12:00 UTC (08:00-20:00 LST) 02 Aug 2017 (grey to white areas represent cloud observed by FengYun-4 satellite; the asterisk denotes the location of Fangshan of Beijing)

Application of VERTICAL Sounder data in weather analysis



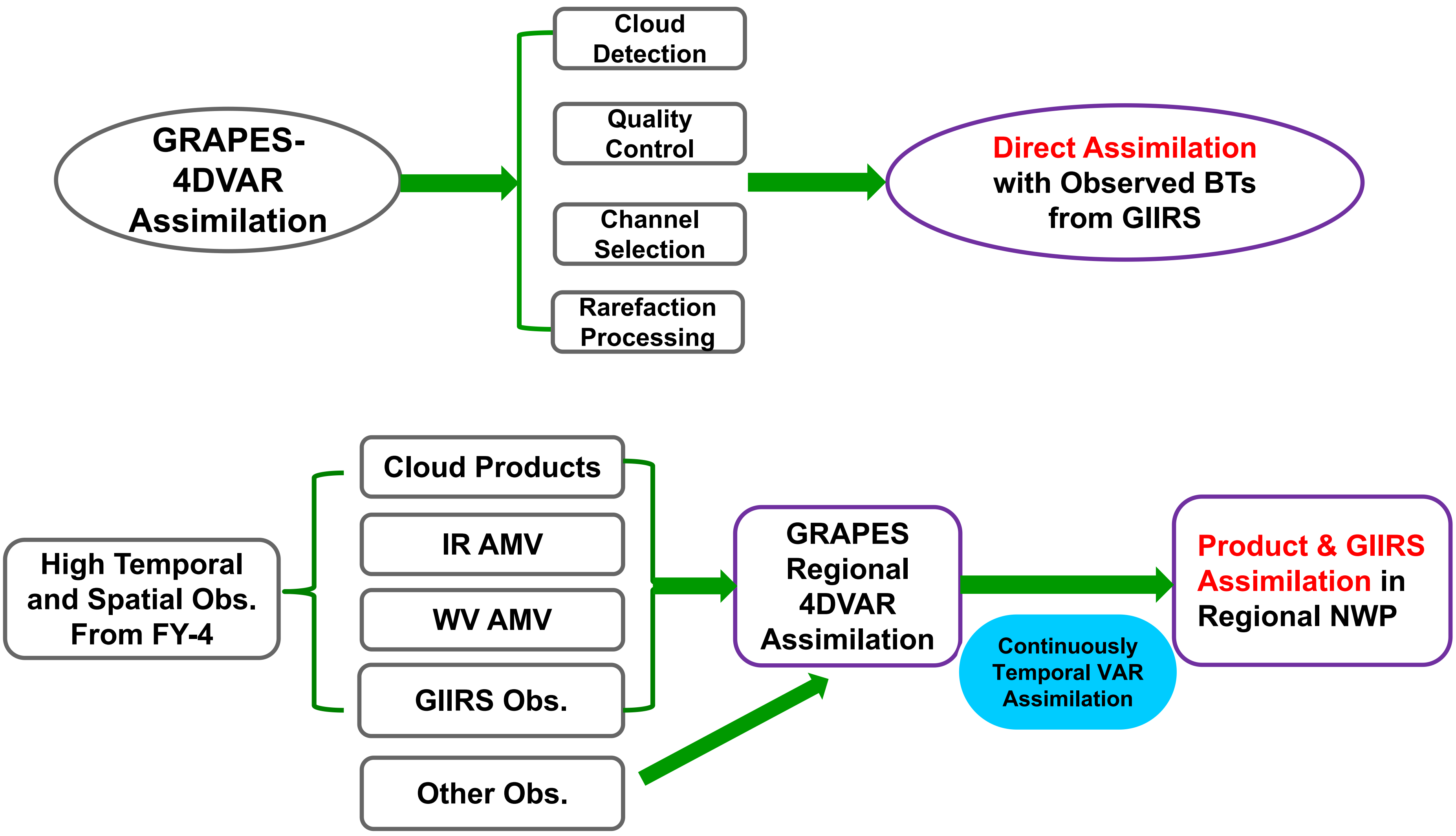
Radar data



GIFTS/HES/IRS

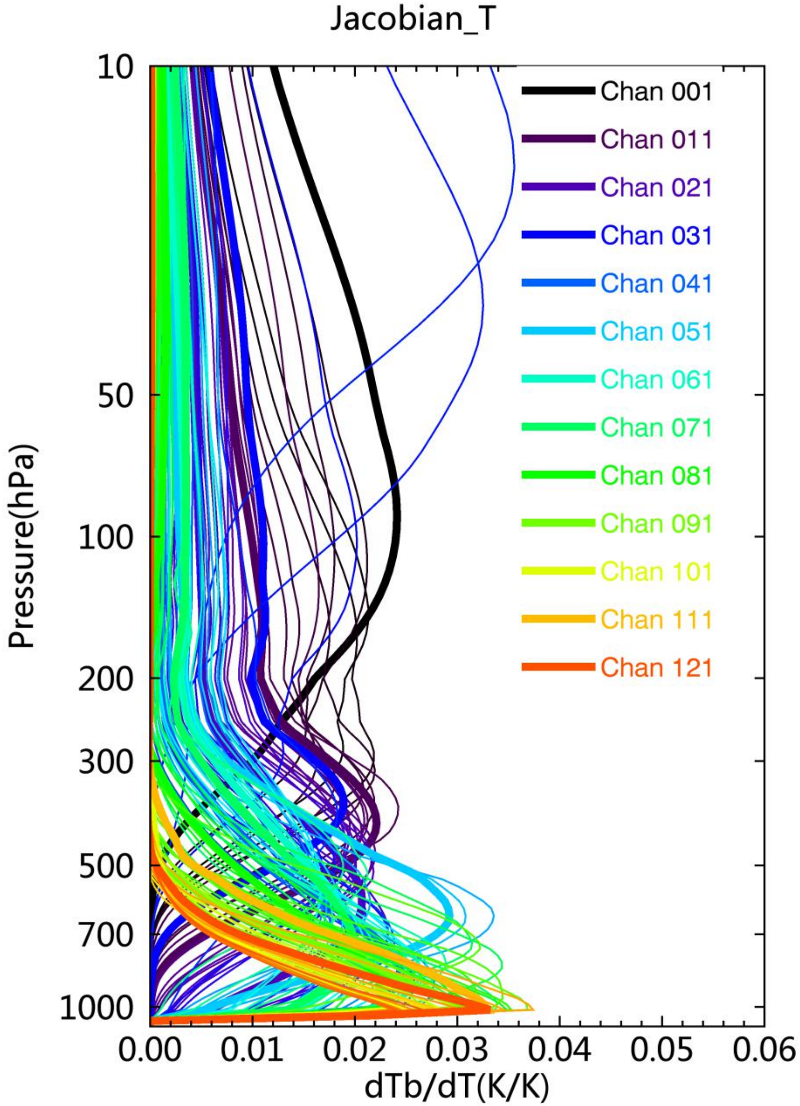
Red: extremely unstable ,
VERTICAL Sounder can detect extremely unstable areas 5-6hrs preceding Radar detection.

GIIRS & Products in Assimilation of NWP

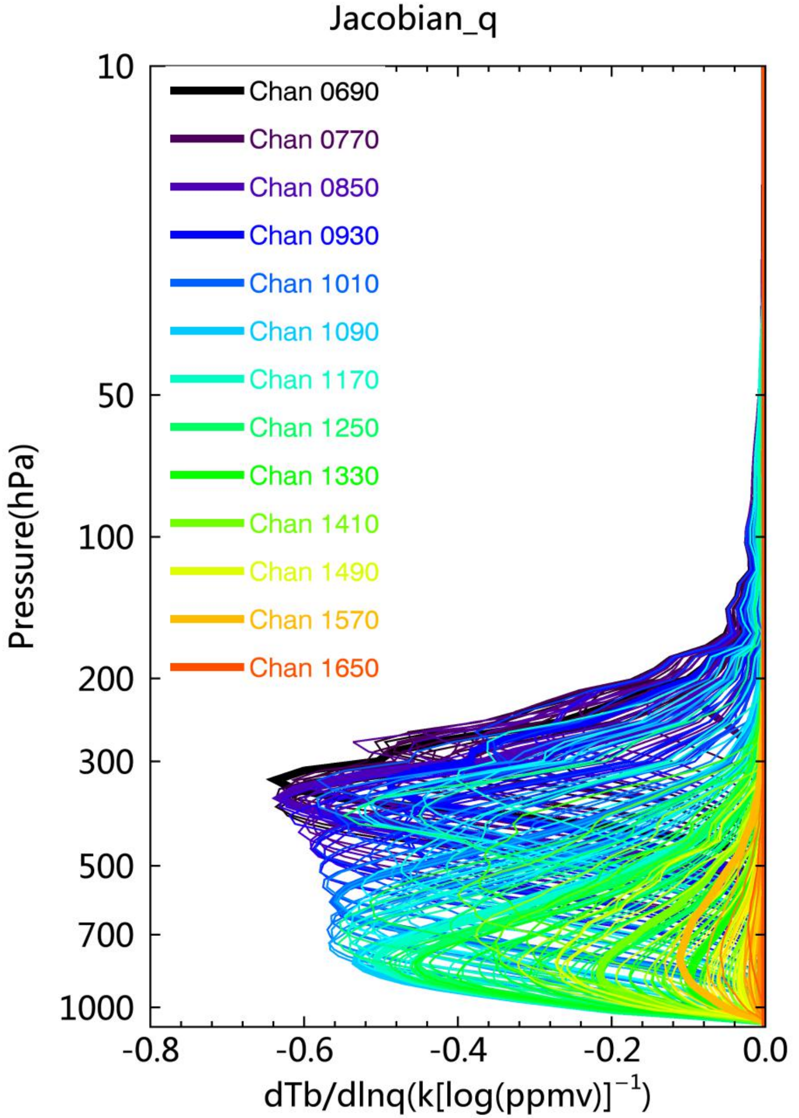


Jacobians of FY-4A GIIRS

689 channels



961 channels

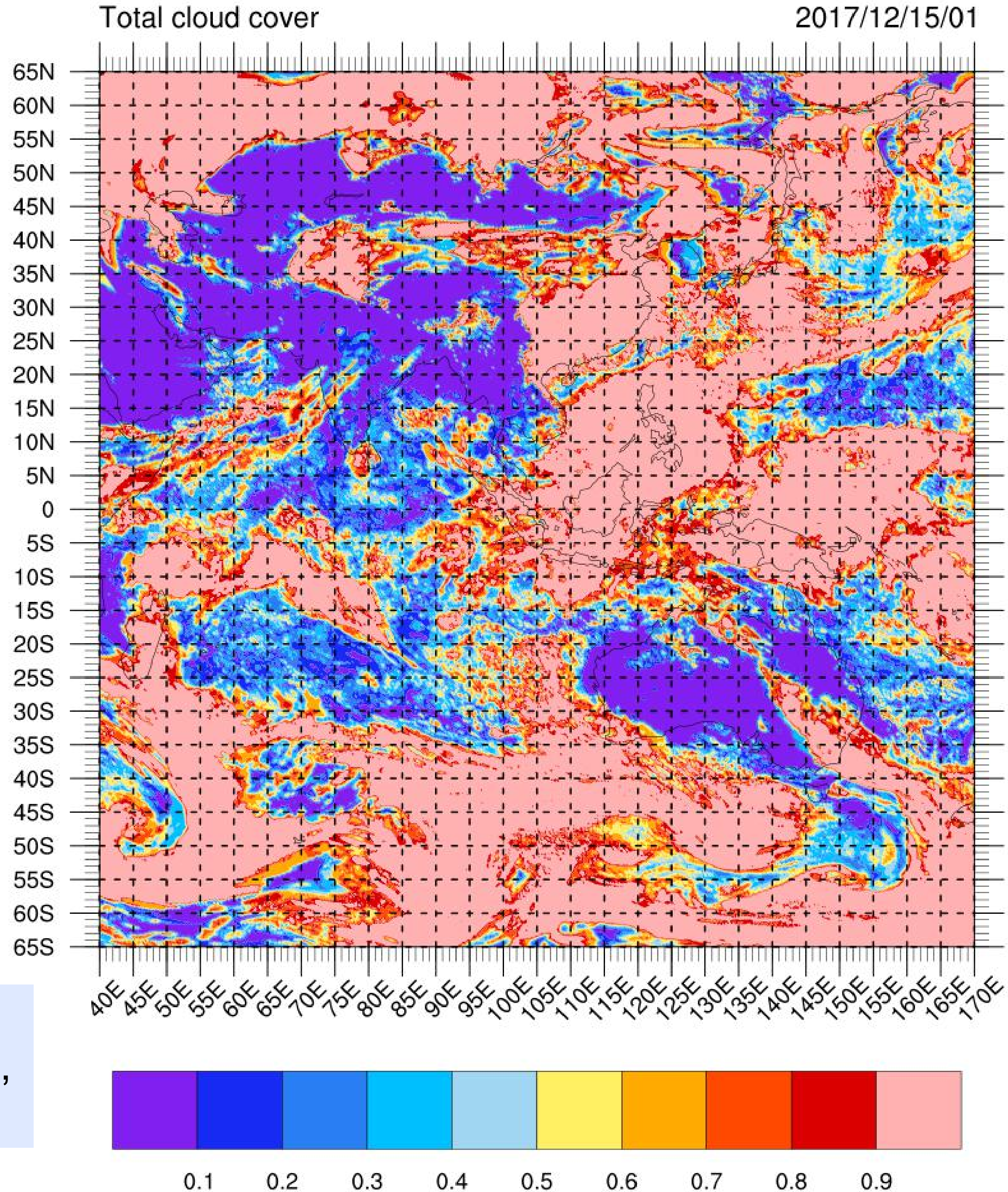


NWP cloud forecasts: High temporal Clear sky IR sounding

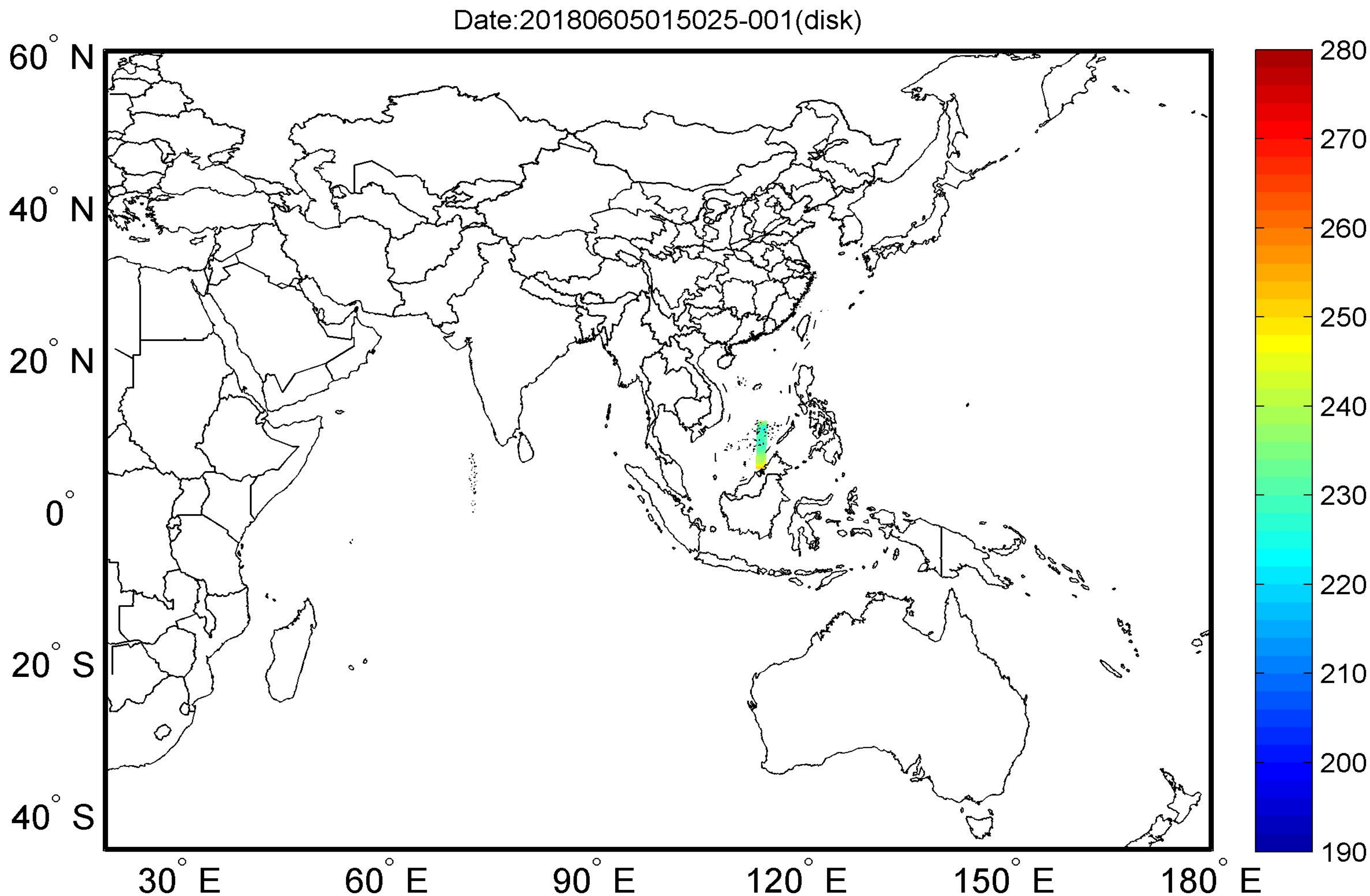
BOTH：
Full disk clear sky sounding;
China regional nowcasting

Adaptive：
Target Area
Sensitive Area

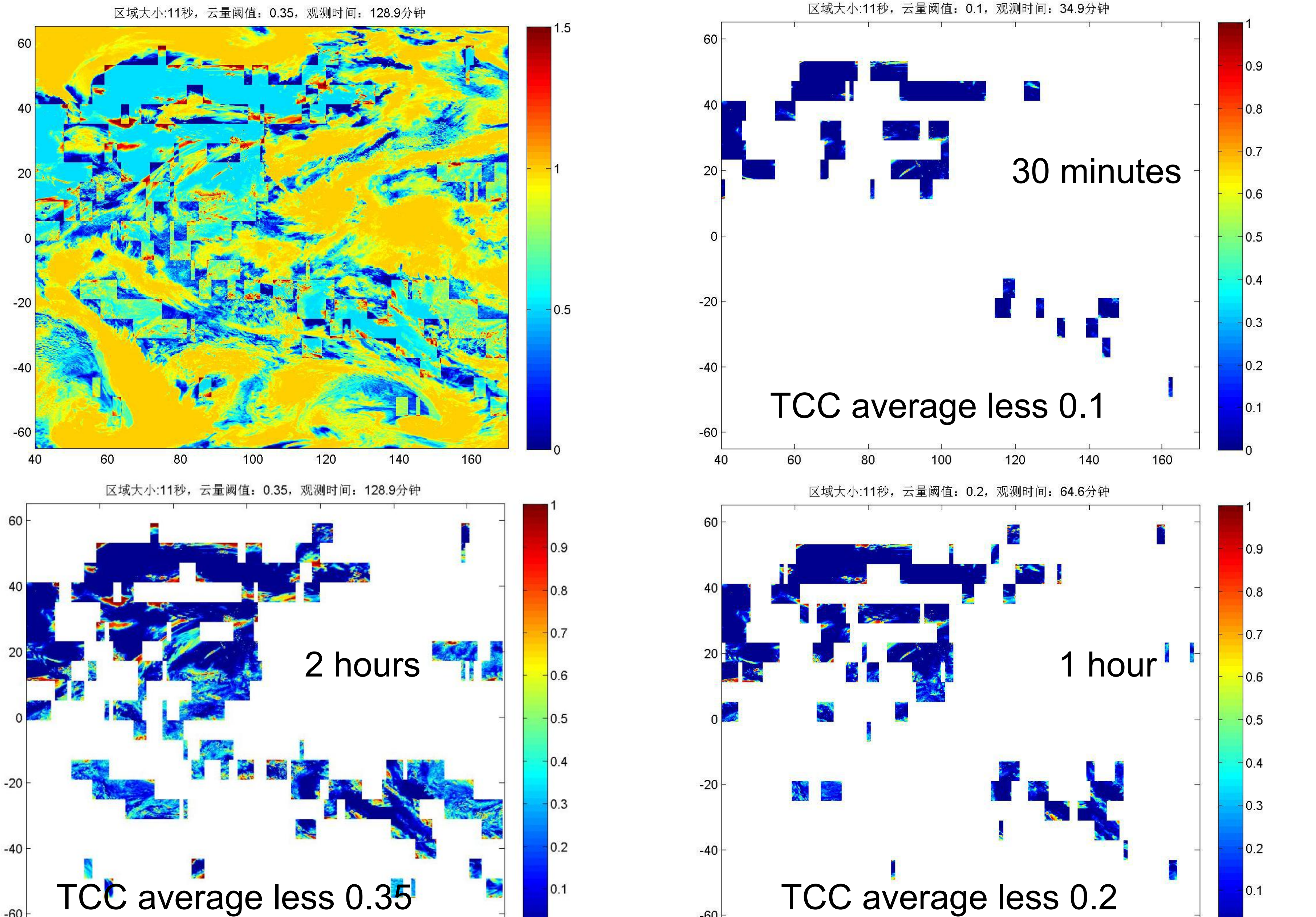
GOAL：
More clear sky IR observarions,
Higher temporal resolution.



FY-4A GIIRS clear sky sounding: Smart Observing mode

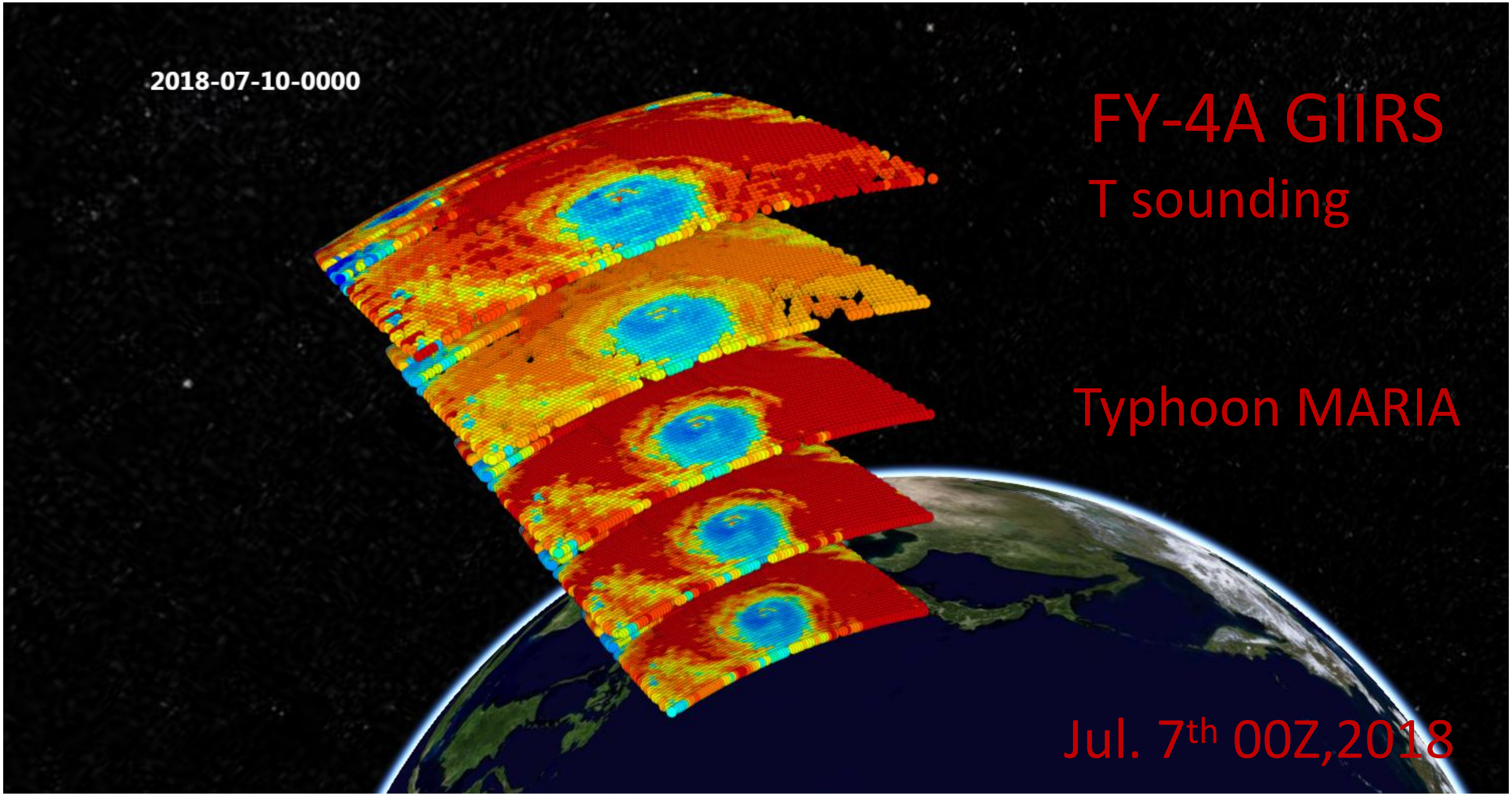


GIIRS "Smart Oberving Mode" based on NWP cloud forecasts

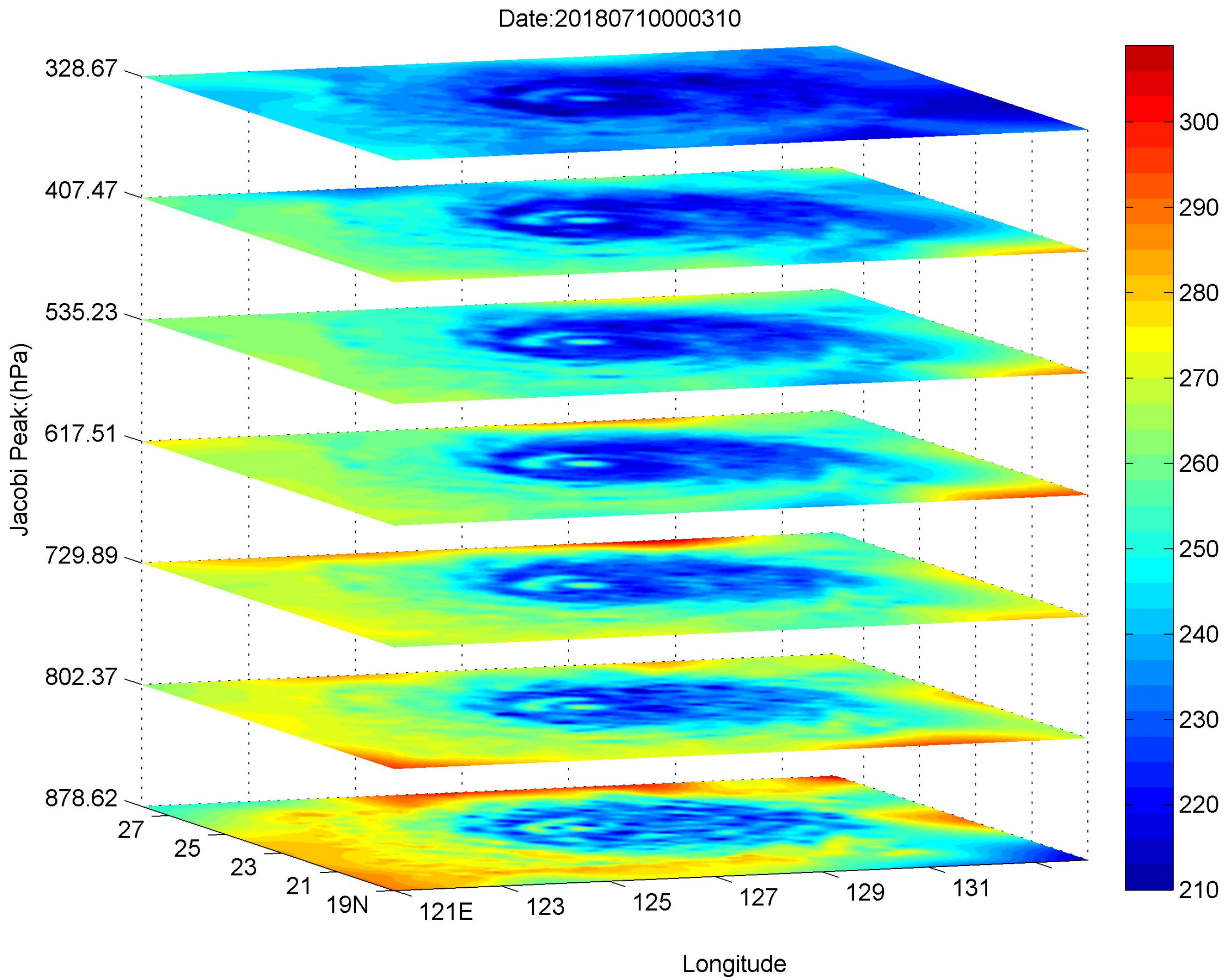


Han W., Zhang Z.Q. et al:2018

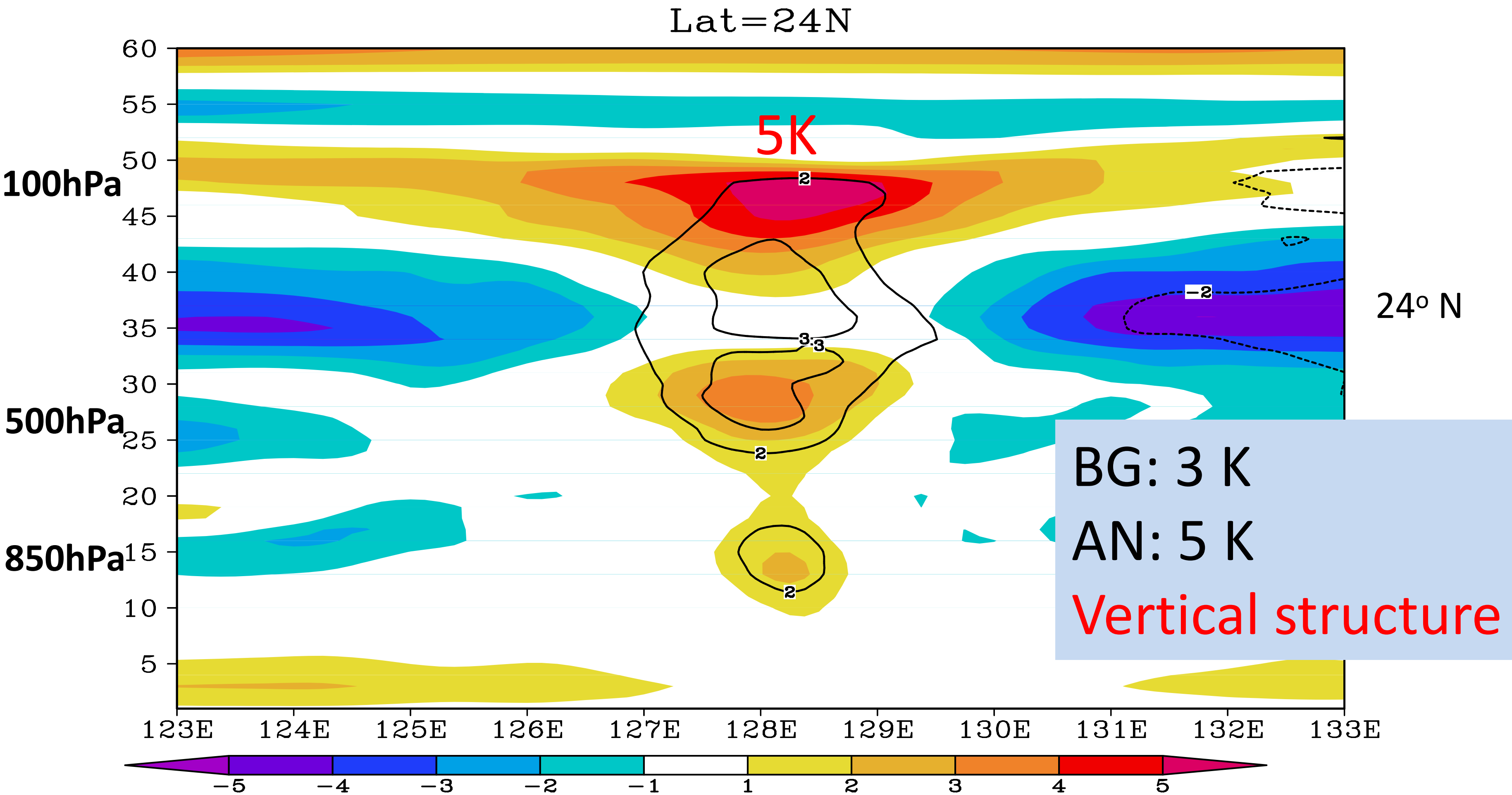
Starting 0800Z (Beijing Time) 10 July 2018 GIIRS provides observations every 15 minutes



FY-4A GIIRS humidity sounding (Every 15 minutes)



Impact of assimilating high temporal GIIRS observations on analysis: Warm core is enhanced

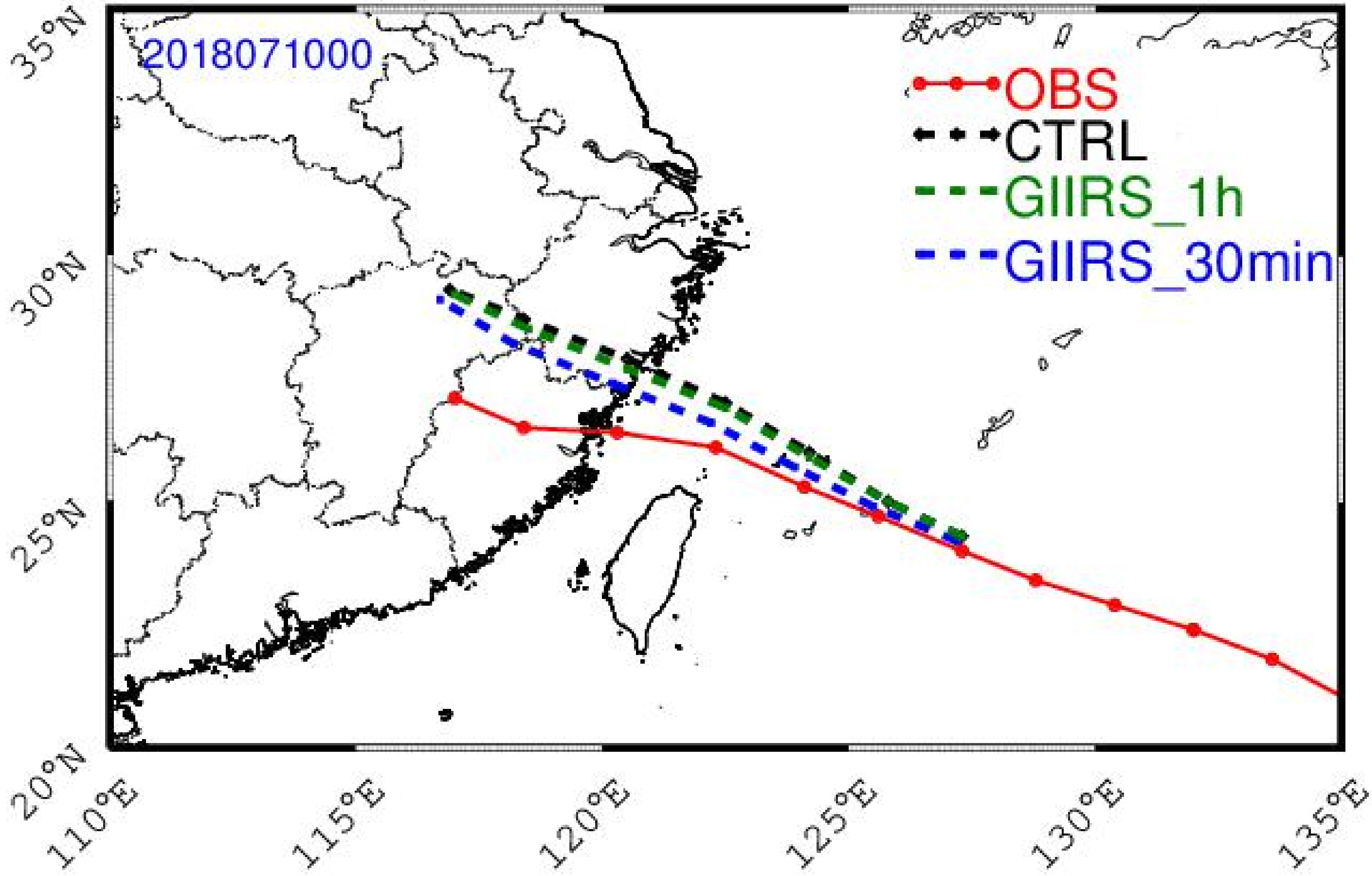


0500 Z 10 July 2018 (Beijing Time)

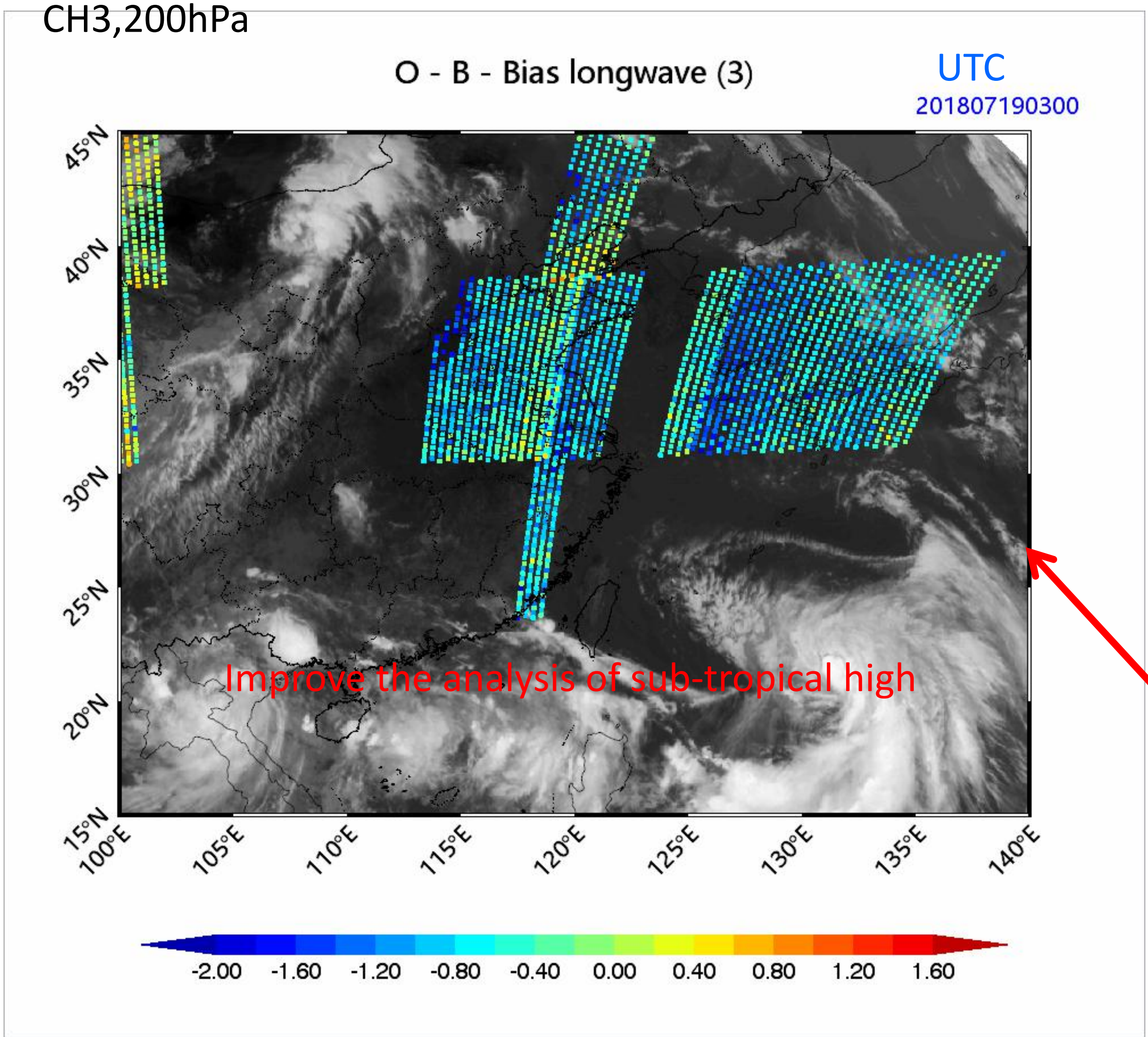
Contour : Temp BG departure

Color： Temp AN departure

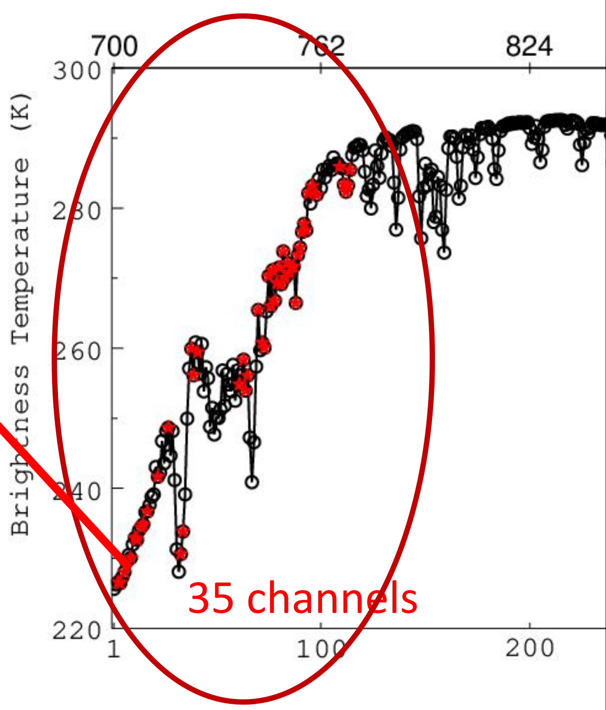
Impact of GIIRS high temporal observations on Typhoon Maria forecasts (72-h)



Assimilation of GIIRS in GRAPES 4D-Var: Typhoon Ambil case



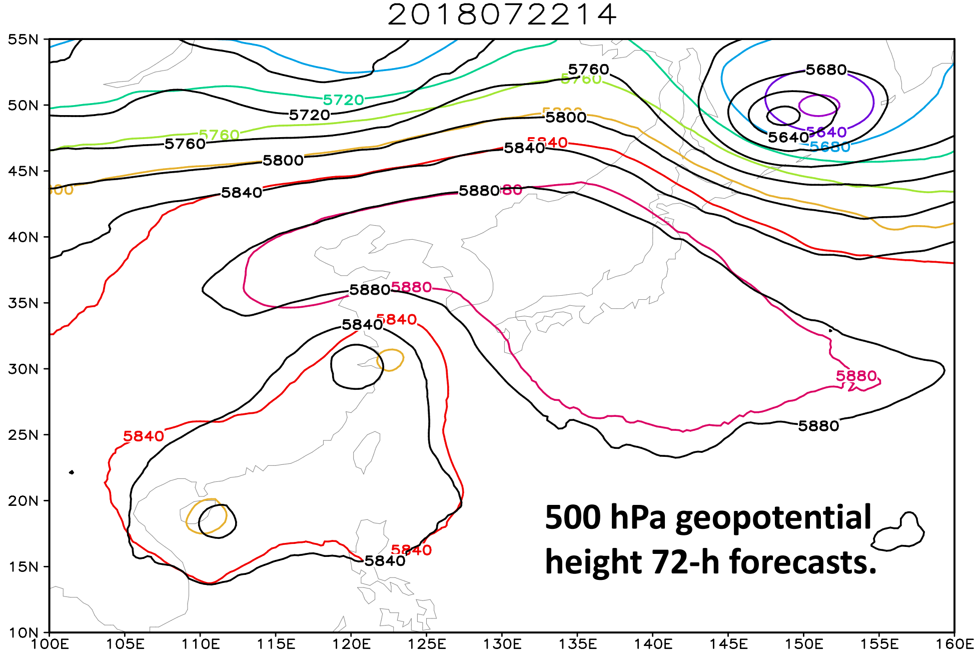
6 hour assimilation time window
35 temperature detection channels selected



YIN Ruoying and HAN Wei,2018

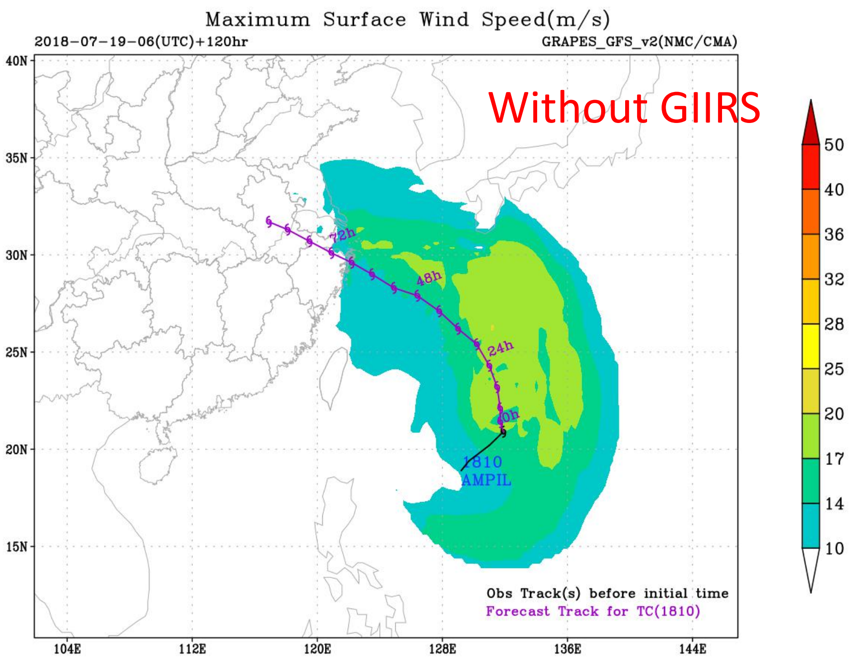
Impact of GIIRS on AMPIL forecasts: improved sub-tropical high, AMPIL intensity and path

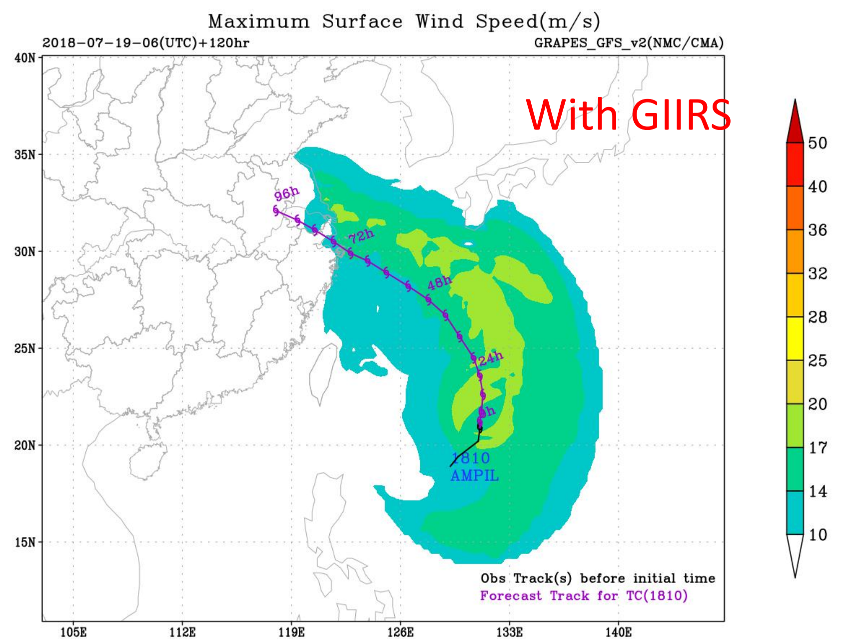
Black contour: without GIIRS data



Red contour: GIIRS data are assimilated

Reduced sub-high strength





AMPIL's Maximum wind speed and path forecasts

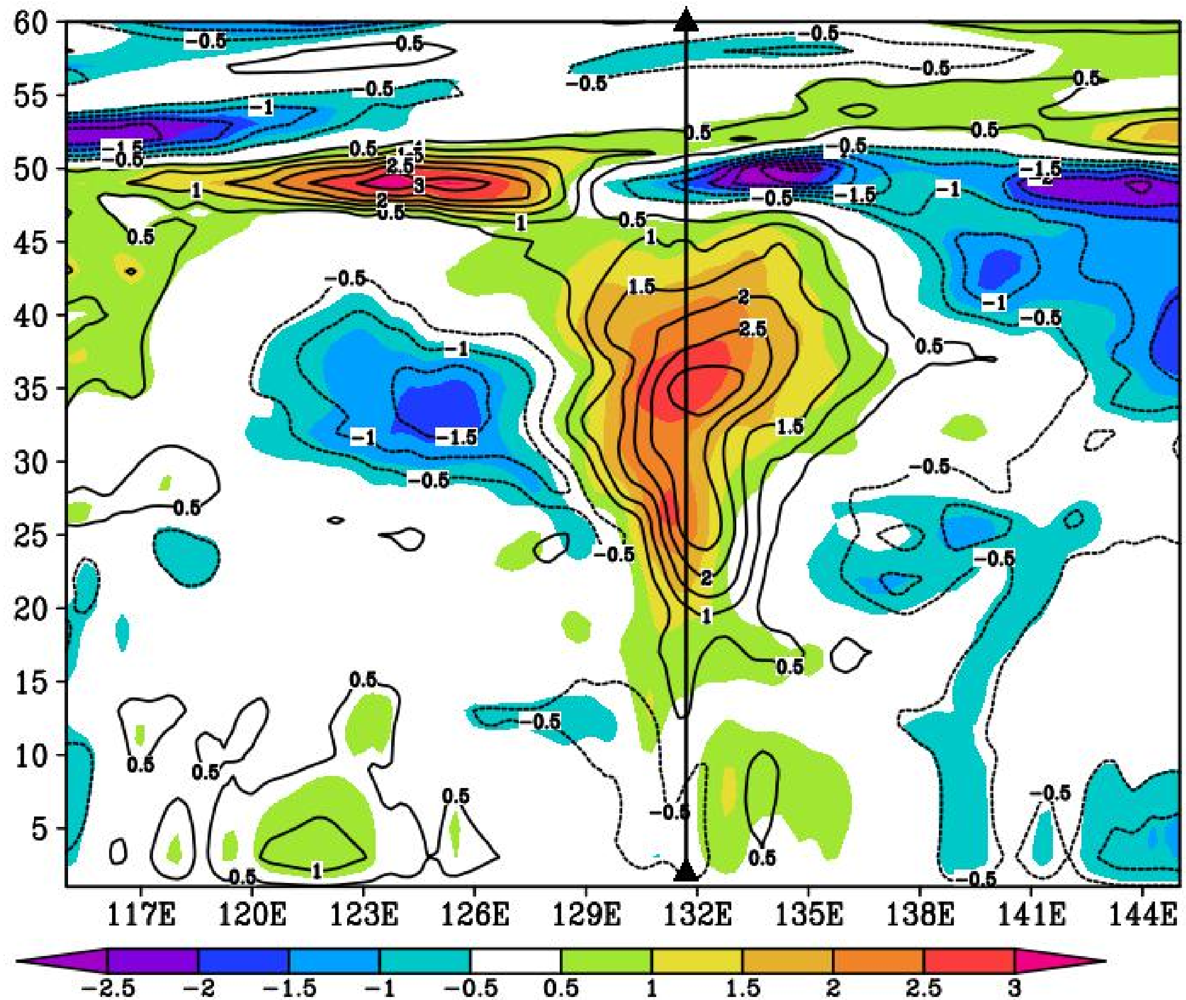
Impact of assimilating high temporal GIIRS observations on AMPIL analysis: **Position is more closer to reality**

Typhoon center position:**20.6N， 131.7E**

300 hPa

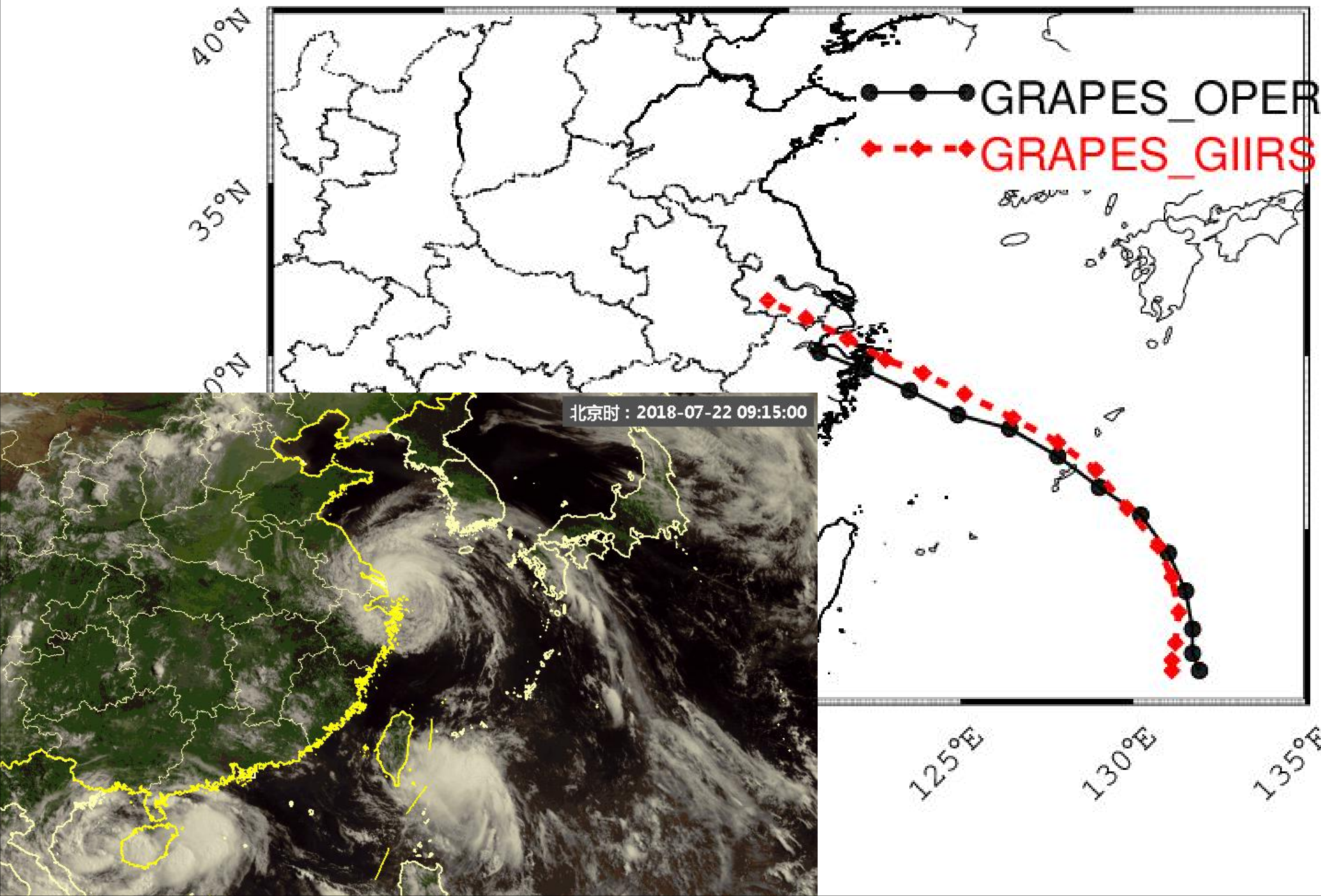
color：
GRAPES_4DVAR+GIIRS

Contour：
GRAPES_4DVAR



Vertical distribution of temperature departure at 11 Z on 19 July 2018 (20.6N)

Impact of assimilating high temporal GIIRS observations on AMPIL forecasts



2. The Operational Methods in TC Analysis
Dvorak Technique

- The primary method of TC monitoring for more than 30 years
- It is still used in many TC operational center. Dvorak technique has been more than a critical analysis and forecasting tool.

Vernon Dvorak in late 1970s

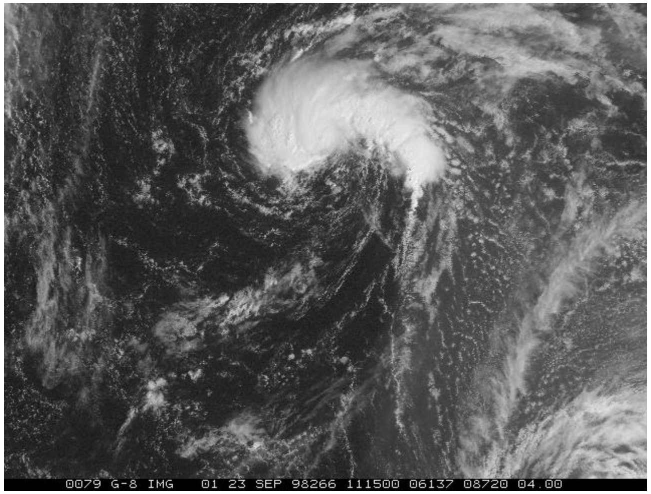
Basics of Dvorak Technique

- Rely on 2 kinematic & 2 thermodynamic properties
- Vorticity (kinematic): organization of clouds
- Vertical wind shear (kinematic): degree of distortion of the vorticity
- Convection (thermodynamic): for cloud pattern recognition & scene type assignment
- Core temperature (thermodynamic): indicates strength of the TC's inner core

Four Basic Patterns

1. Curved Band (VIS and IR)

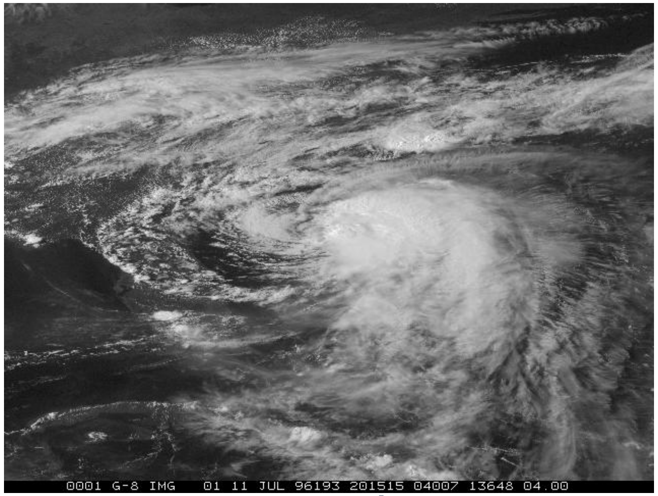
In the early stage of TC, one or more cloud bands and several spiral clouds were rotated to a common center. When the curved cloud belt rotates half circle, the tropical cyclone reaches the tropical storm intensity; when the curved cloud belt rotates 3/4 circle, a strong tropical storm is reached; when the curved cloud belt rotates closed, the typhoon intensity is reached. The parameters of the curved cloud band are described by Banding feature(BF). The value of BF depends on the number of turns around the center of the cloud band and the width of the cloud band.



Curved band (comma)

2. Shear

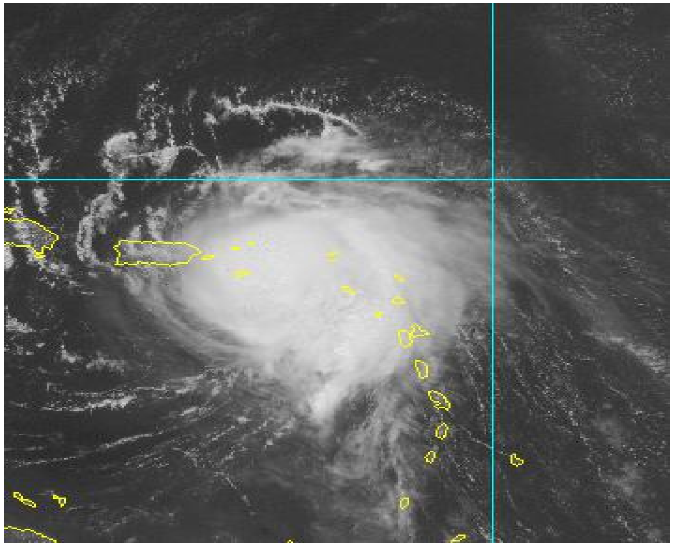
When the TC moves to the strong high-altitude wind shear zone, the high convective cloud system of TC is biased to the leeward side.



Shear

3. Central Dense Overcast, CDO, (VIS)

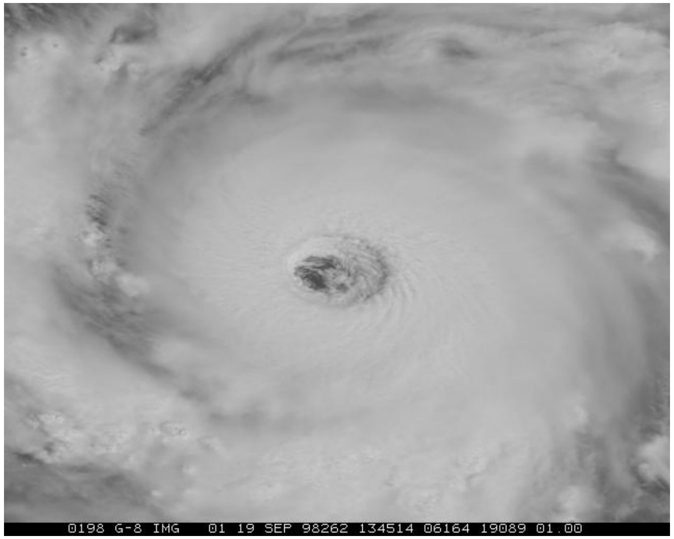
On the visible or infrared cloud image, a dense cloud area appears at the center of curved band or around the eye area. This is the central dense cloud area. Its size and boundary determine the value of the Central Feature number. The larger the CDO, the clearer the boundary and the larger the CF.



CDO

4. Eye or Banding Eye(VIS and IR)

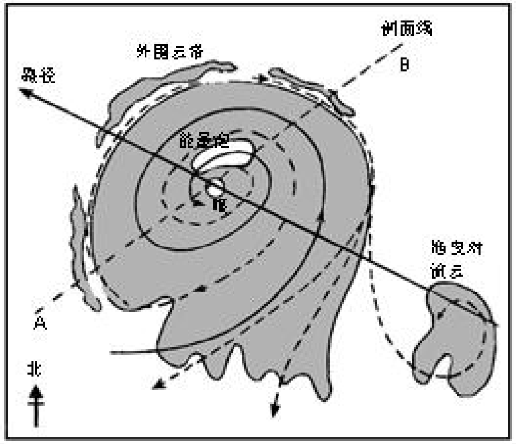
The typhoon eye is a parameter that reflects the intensity of Typhoon. The characteristics are represented by the shape and size of the eye, and the characteristics of the surrounding cloud system.



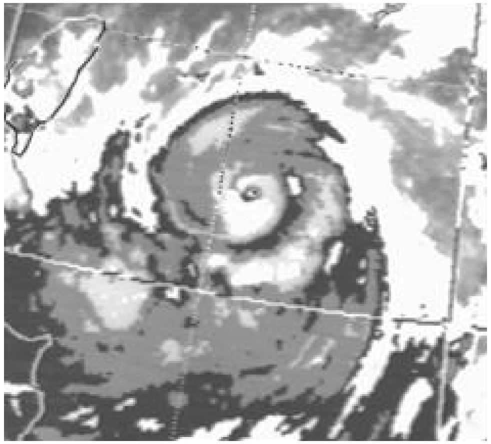
Eye

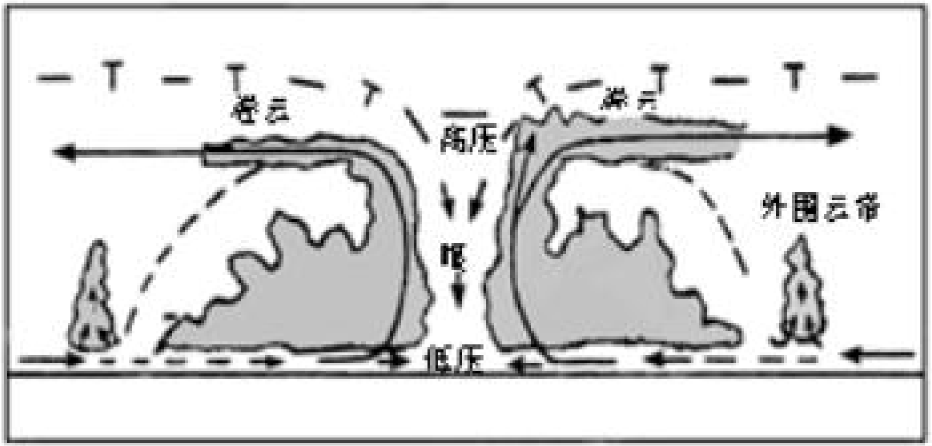
Basic structure of tropical cyclone

The horizontal distribution of tropical cyclones is divided into three parts: (1) the center is a dark cloud-free eye area; (2) the continuous dense cloud area around the eye area; (3) the spiral cloud belt around the dense cloud area.



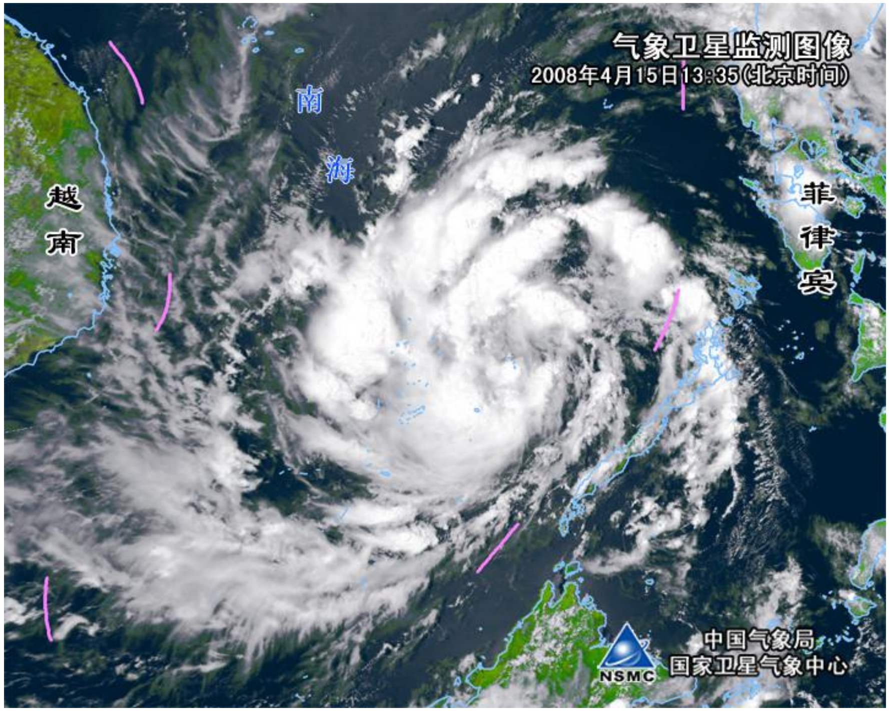
(a)台风云系的水平分布(—► 低空风, --► 高空风)

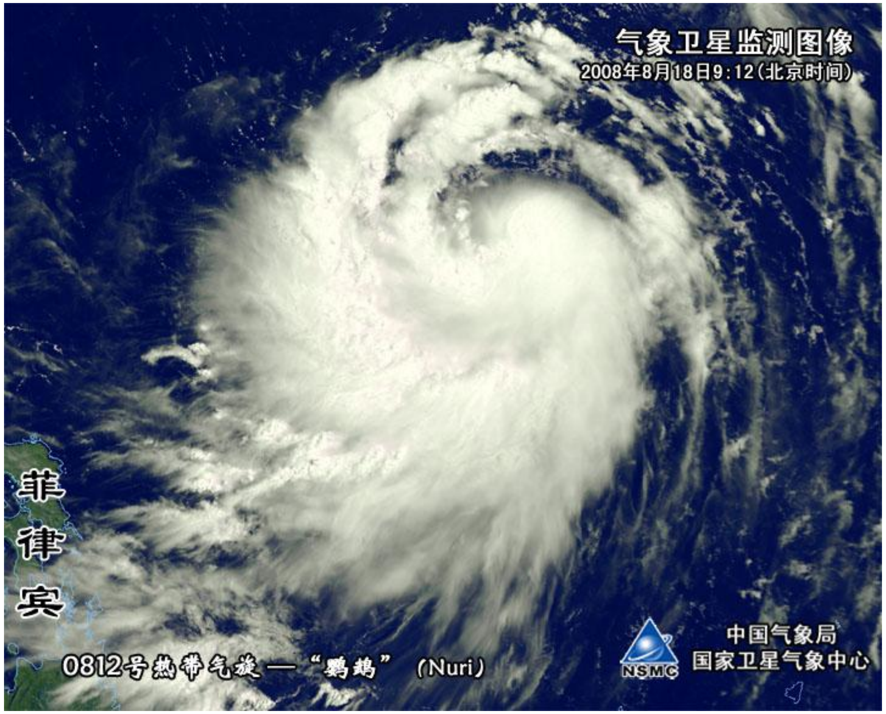

(c) 增强红外云图上的台风云系
(1987 年 7 月 13 日 20 时)



(b) 台风云系的垂直分布

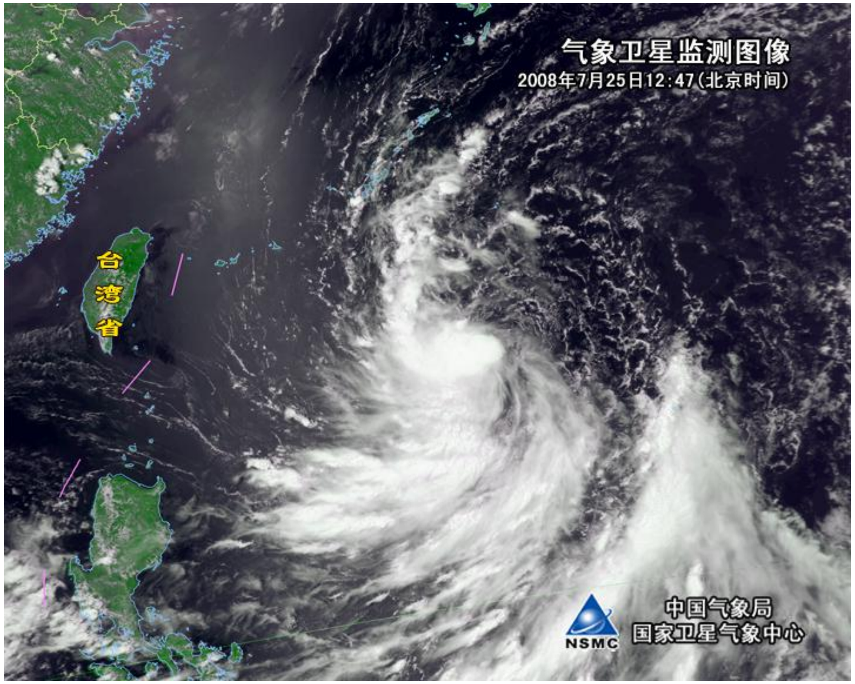
TC Patterns in Primary and development stage--- Curved Band

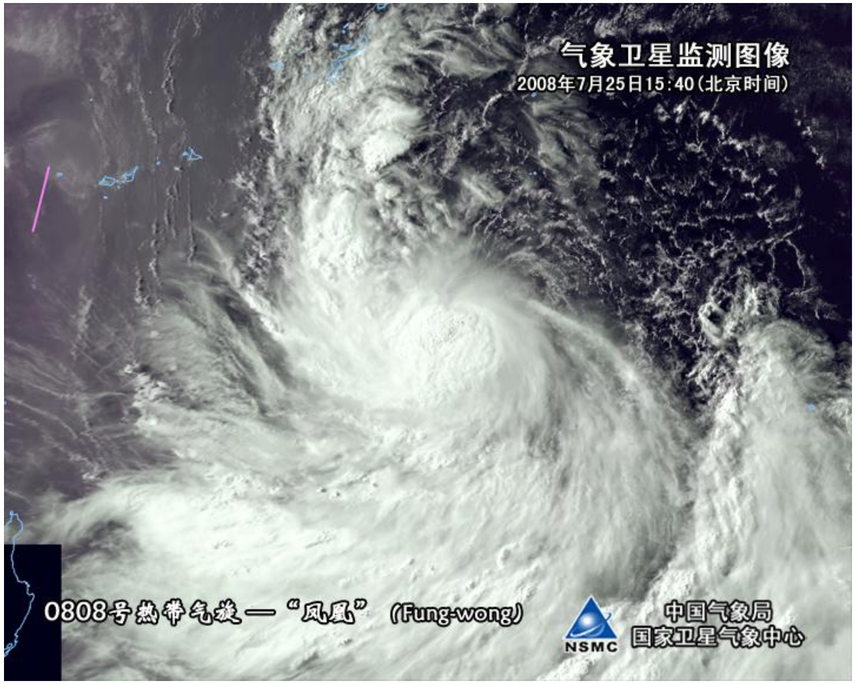




The curved band type is a common cloud type in the development stage of tropical cyclones, and consists of one or more comma-like convective clouds and high-level broken clouds .

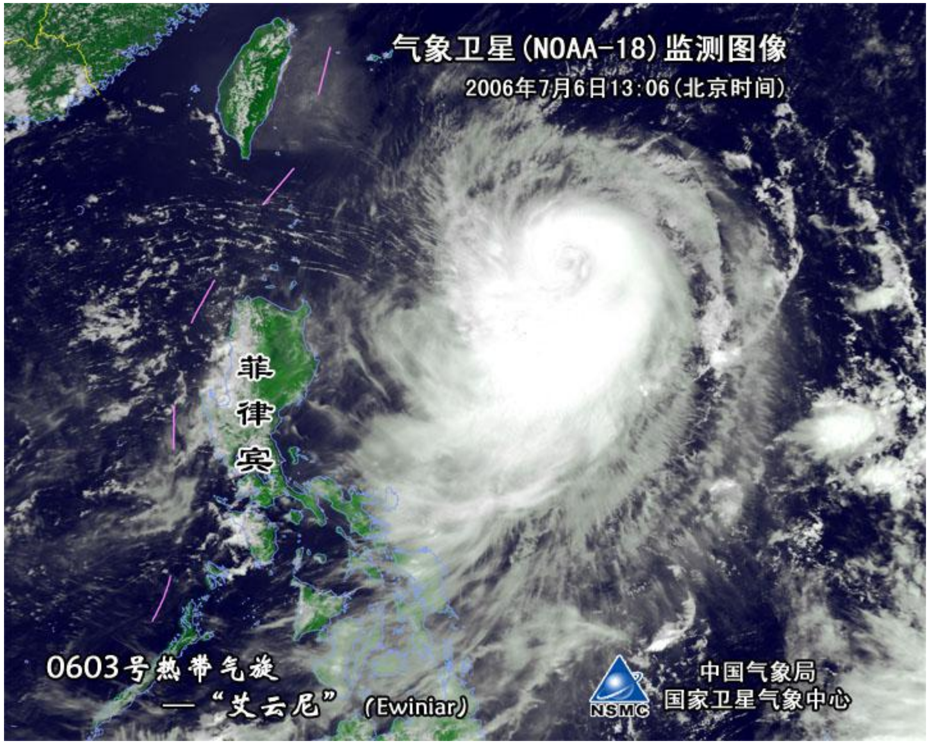
TC Patterns in Primary and development stage--- Shear

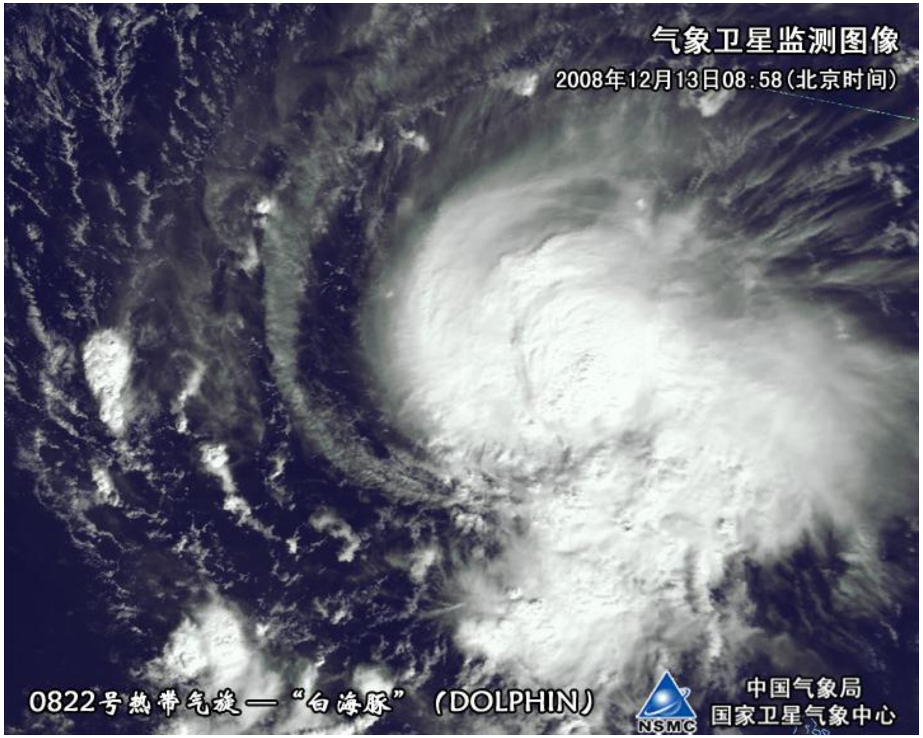




At the primary stage of the TC, the deep convection near the center has not been fully established, and the high and low air flows are inconsistent around the direction, causing the airflow to shear in the vertical direction.

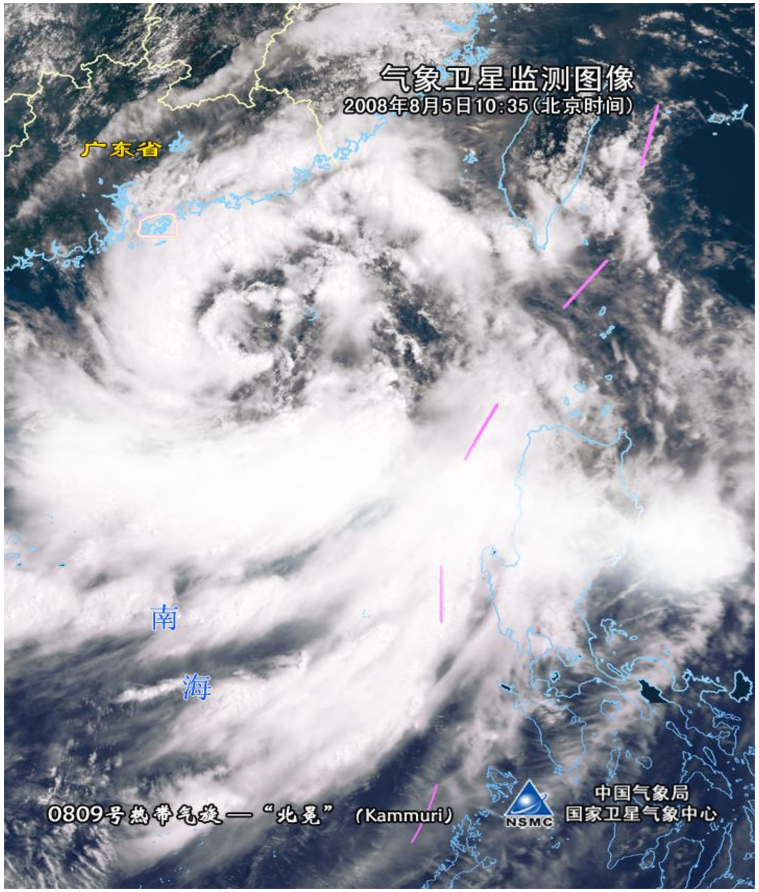
TC Patterns in Primary and development stage---CDO

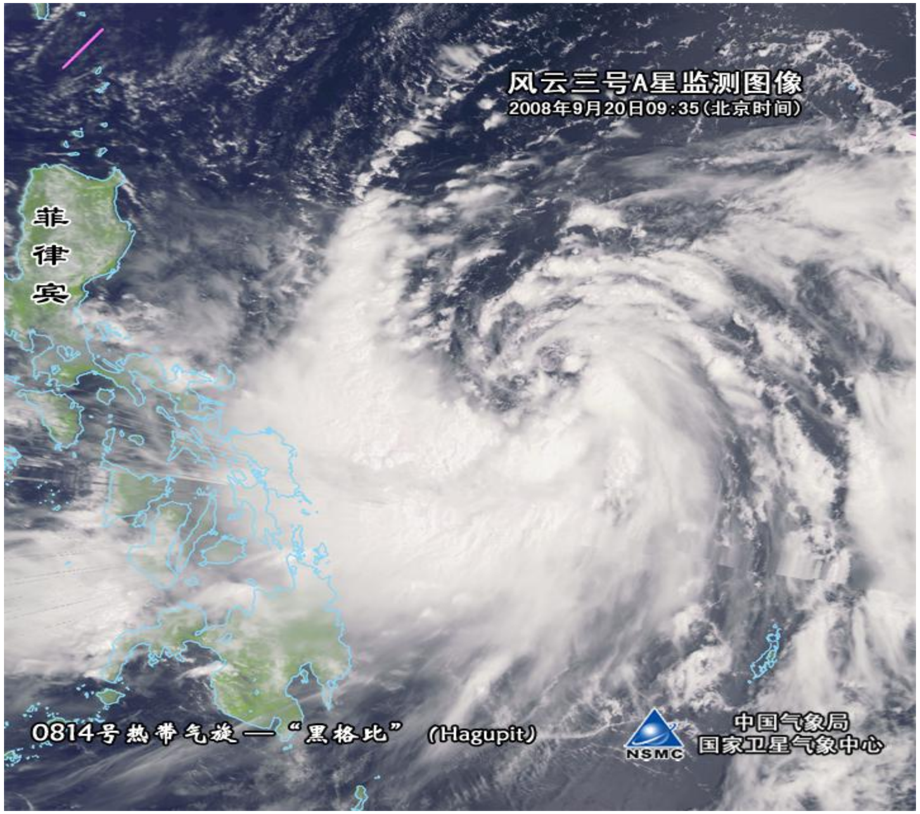




In the development stage, some tropical cyclones have the characteristics of CDO. The curved center of the curved cloud belt is completely covered by the convective cloud.

TC Patterns in mature stage---Banding eye

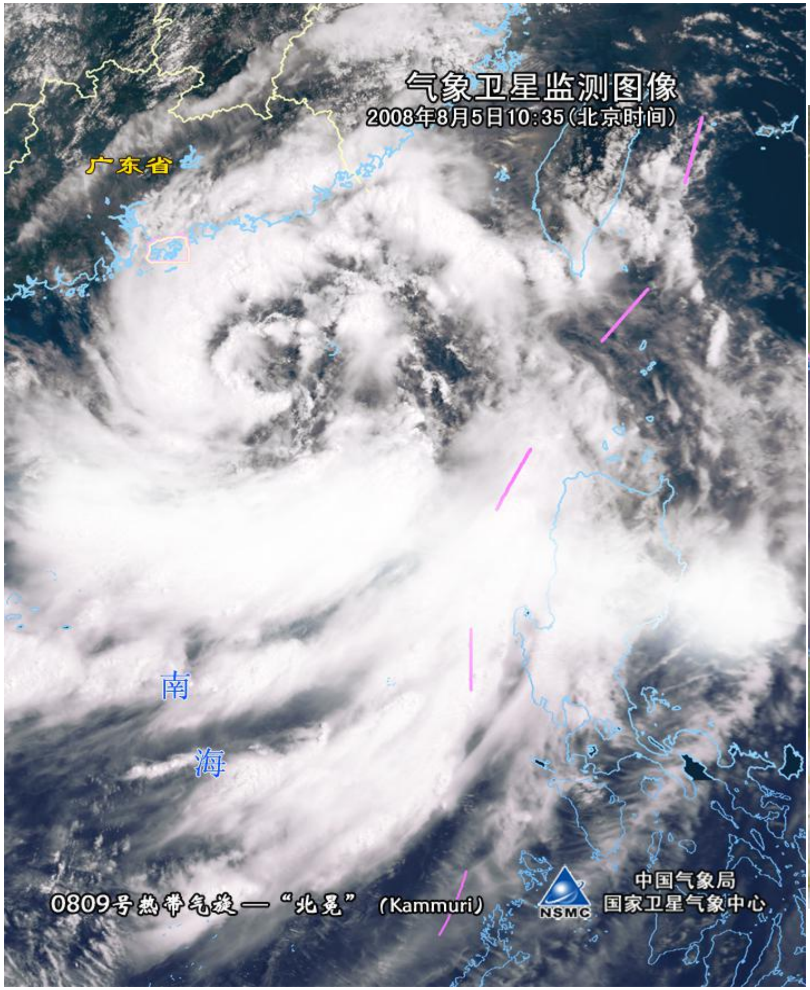


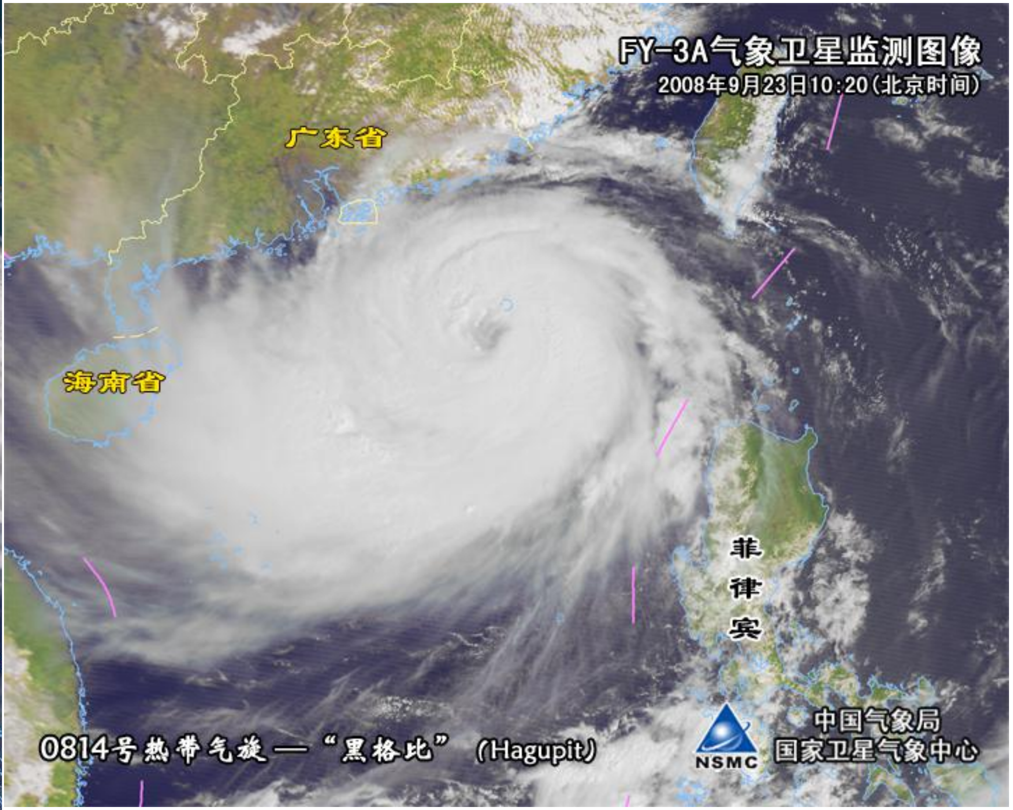


Most tropical cyclones exhibit eye-shaped characteristics at the maturity stage, and the shape of the eye area is an important indicator of the intensity of TC.

At the beginning of the mature stage, the curved band type shows a band-shaped eye area surrounded by clouds. At this time, the TC has reached the typhoon stage.

TC Patterns in mature stage---Irregular eye



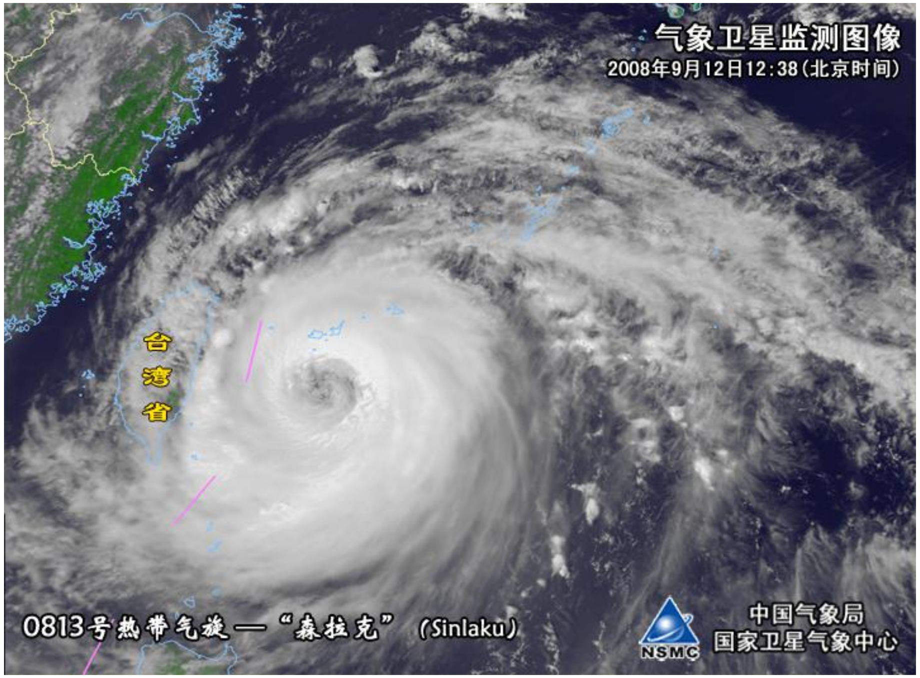


Irregular big eye

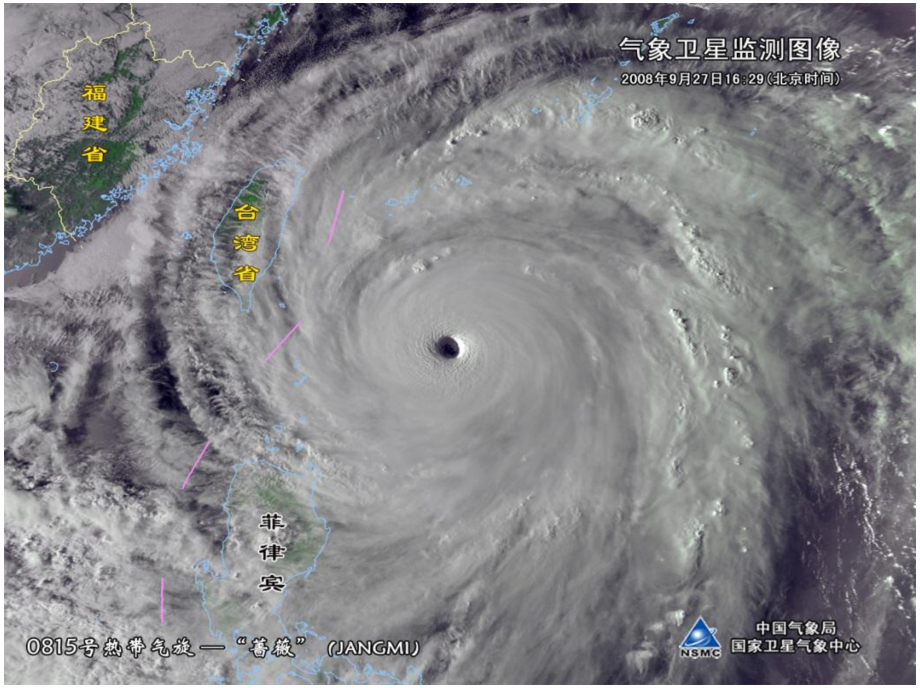
Irregular small eye

The shape and size of the eye reflect the intensity of the tropical cyclone, ie the air pressure and wind speed near the center of the TC.

TC Patterns in mature stage---Regular and smooth eye



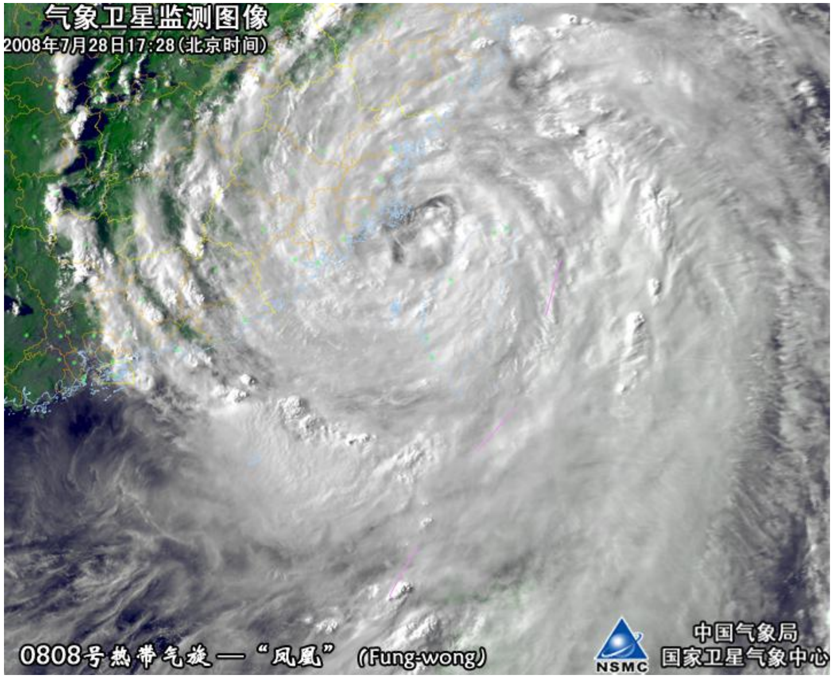
Severe typhoon with smooth big eye

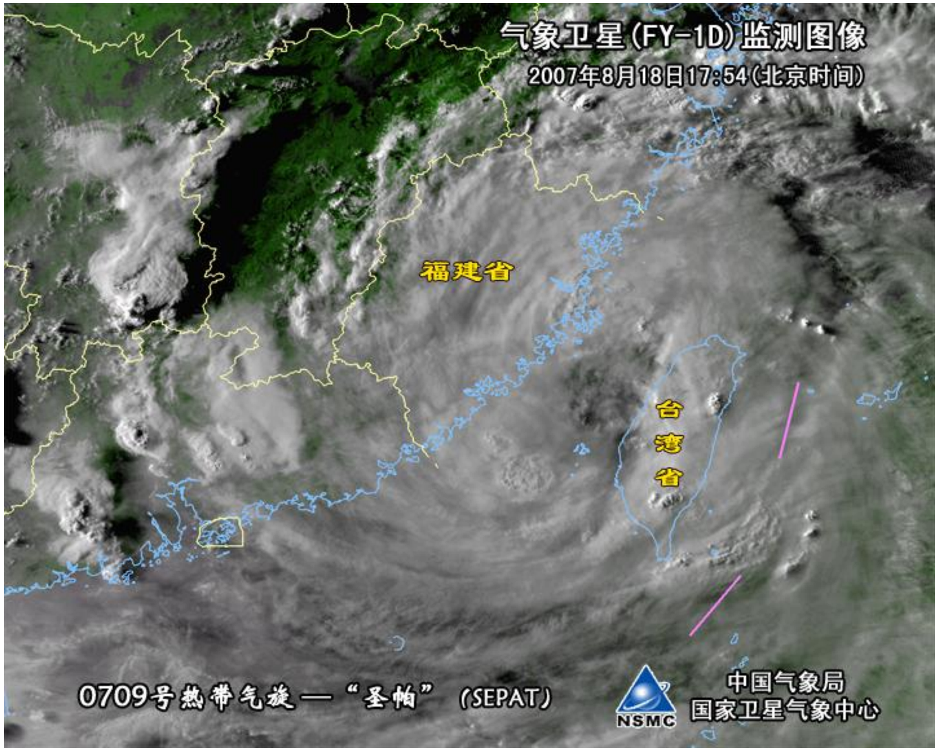


Super typhoon with smooth small eye

The smoothness and size of the eye also reflect the intensity of tropical cyclones.

TC Patterns in weaken stage--- Central packing

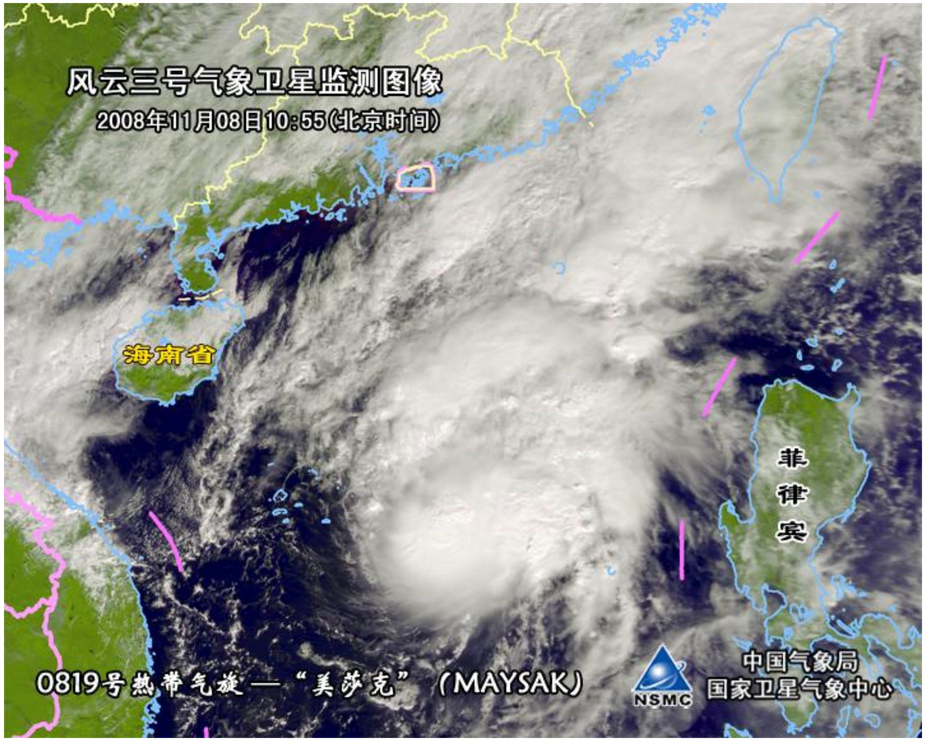


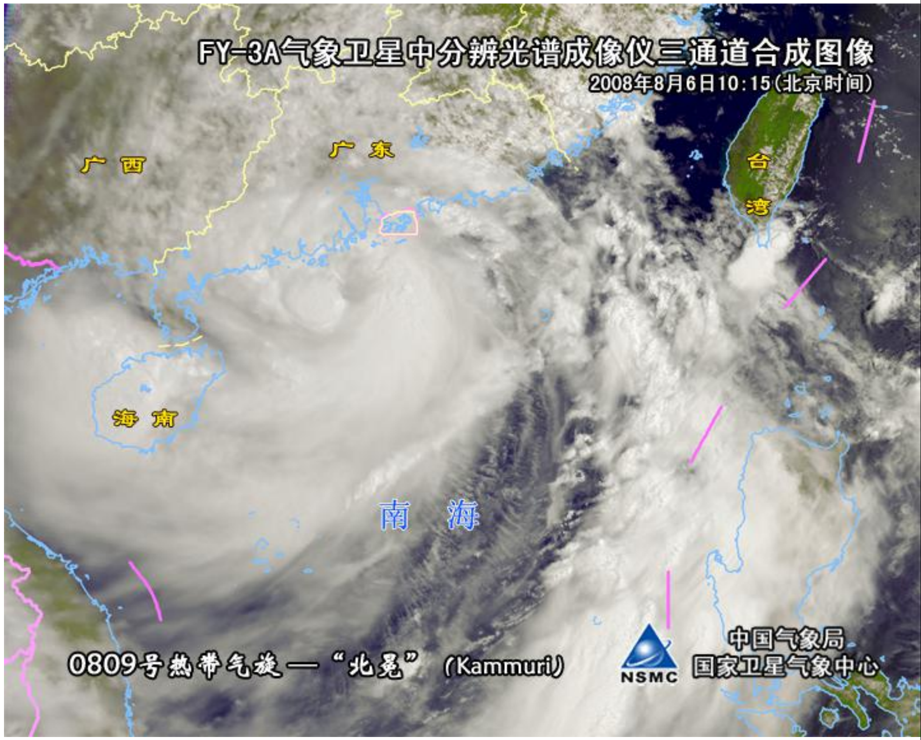


For the eye-type TC, the filling of the eye area and the irregular expansion of the eye shape are important signs of the weakening TC intensity.

TC Patterns in weaken stage--- CDO

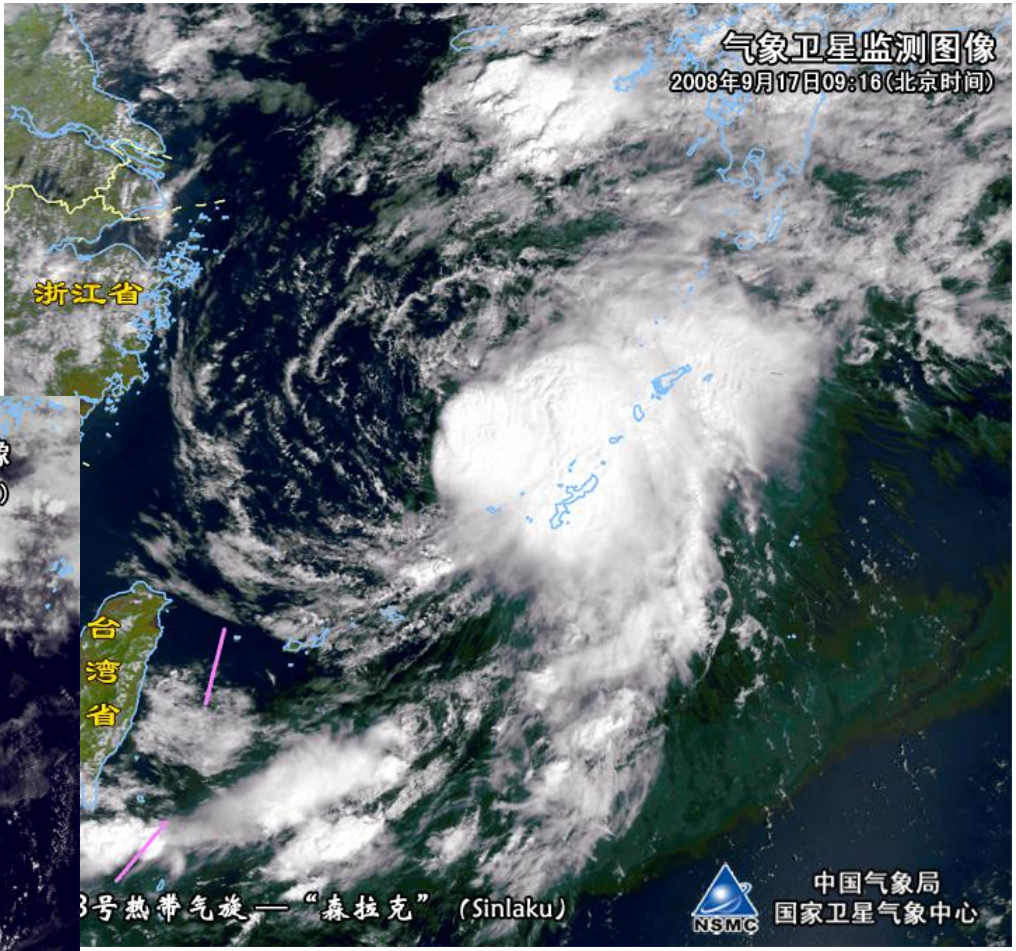
During the weaken stage, the spiral cloud belt of some TC weakened, and a circular cold cloud cluster appeared in the center and gradually expanded.

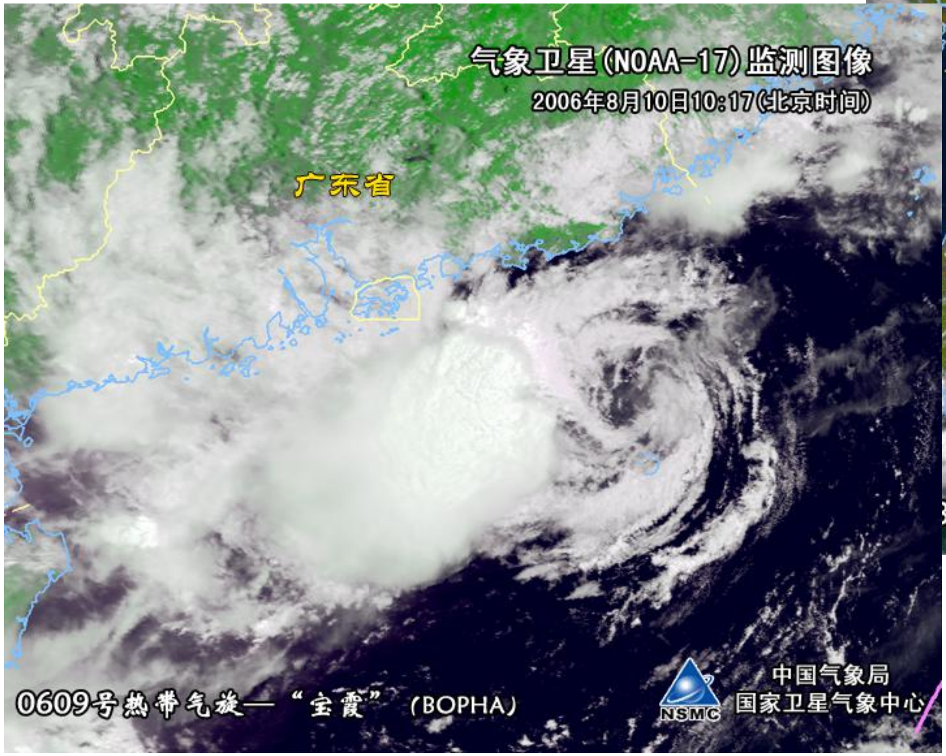




TC Patterns in weaken stage--- Shear

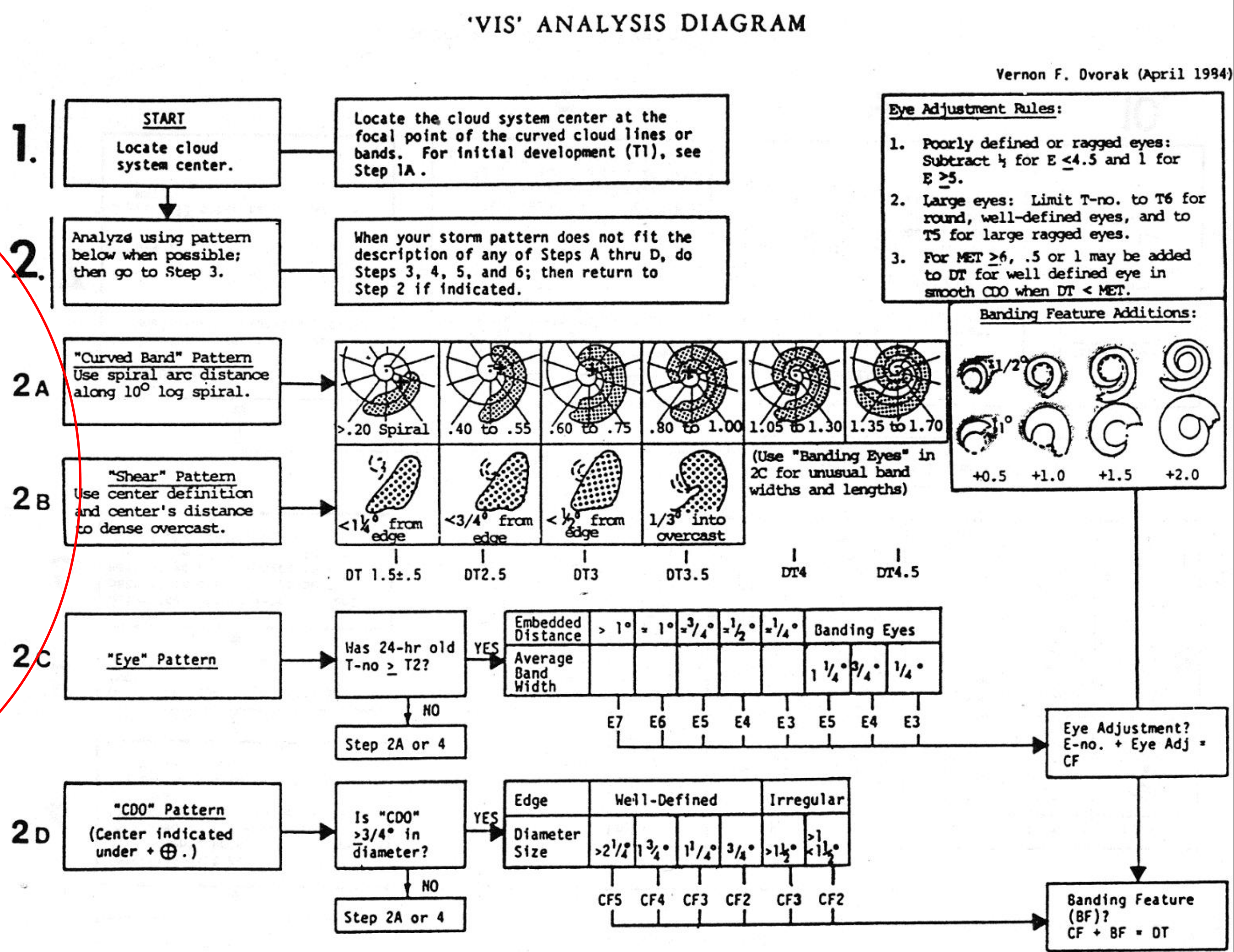
During the weaken stage, some tropical cyclones exhibit damaging effects of wind shear, and high-level convective clouds deviate to the leeward side of the lower center.





Dvorak Technique Procedure

Dvorak (1984)
10 Steps:
1. Locate center
2. Select pattern and assign Data-T Number (DT)



Dvorak Technique Procedure

Dvorak (1984) 10 Steps:

3. Central Cold Cover (CCC; if applicable)

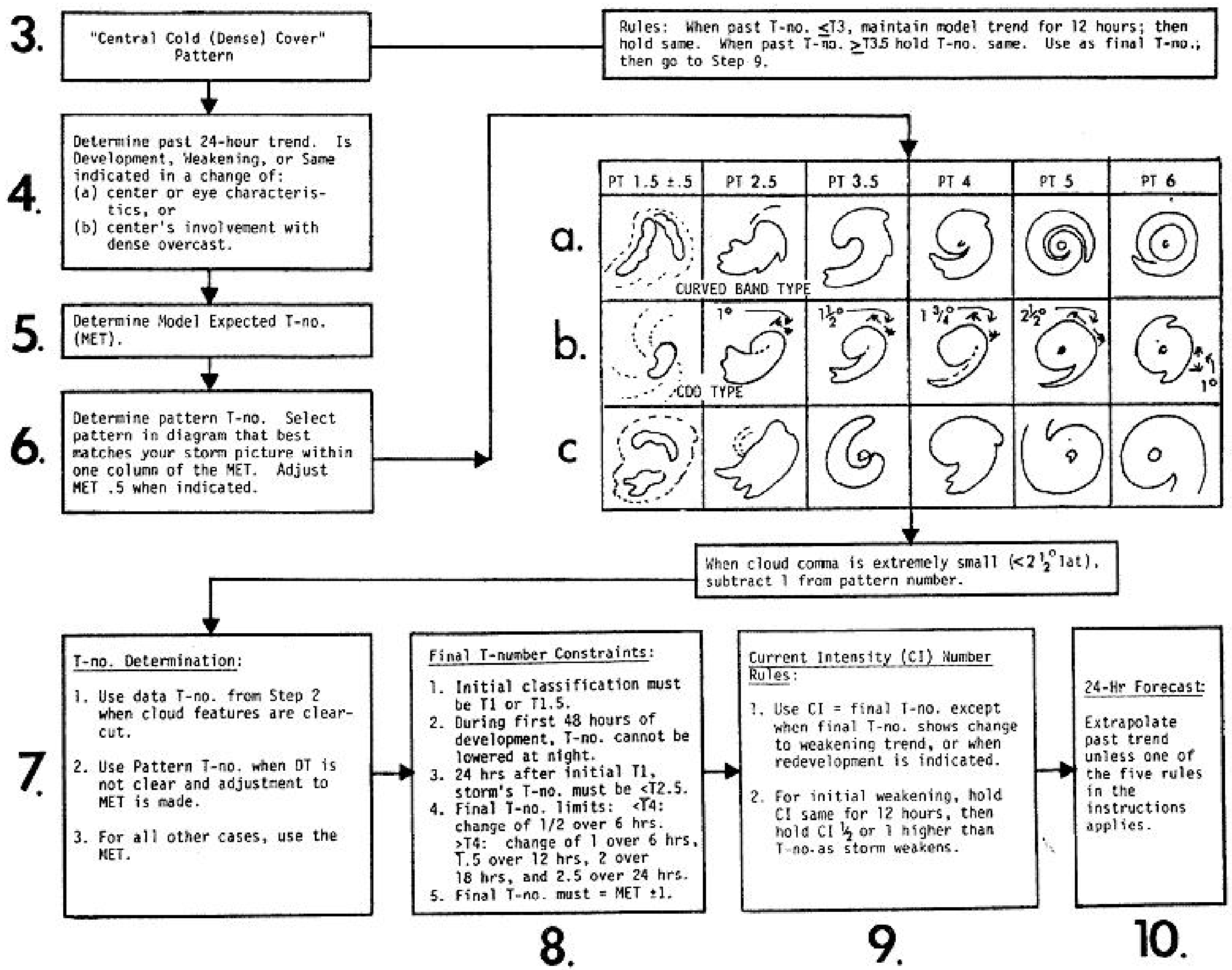
4. Analyze 24-h trend

5. Assign Model Expected T-Number (MET)

6. Assign Pattern T-Number (PT)

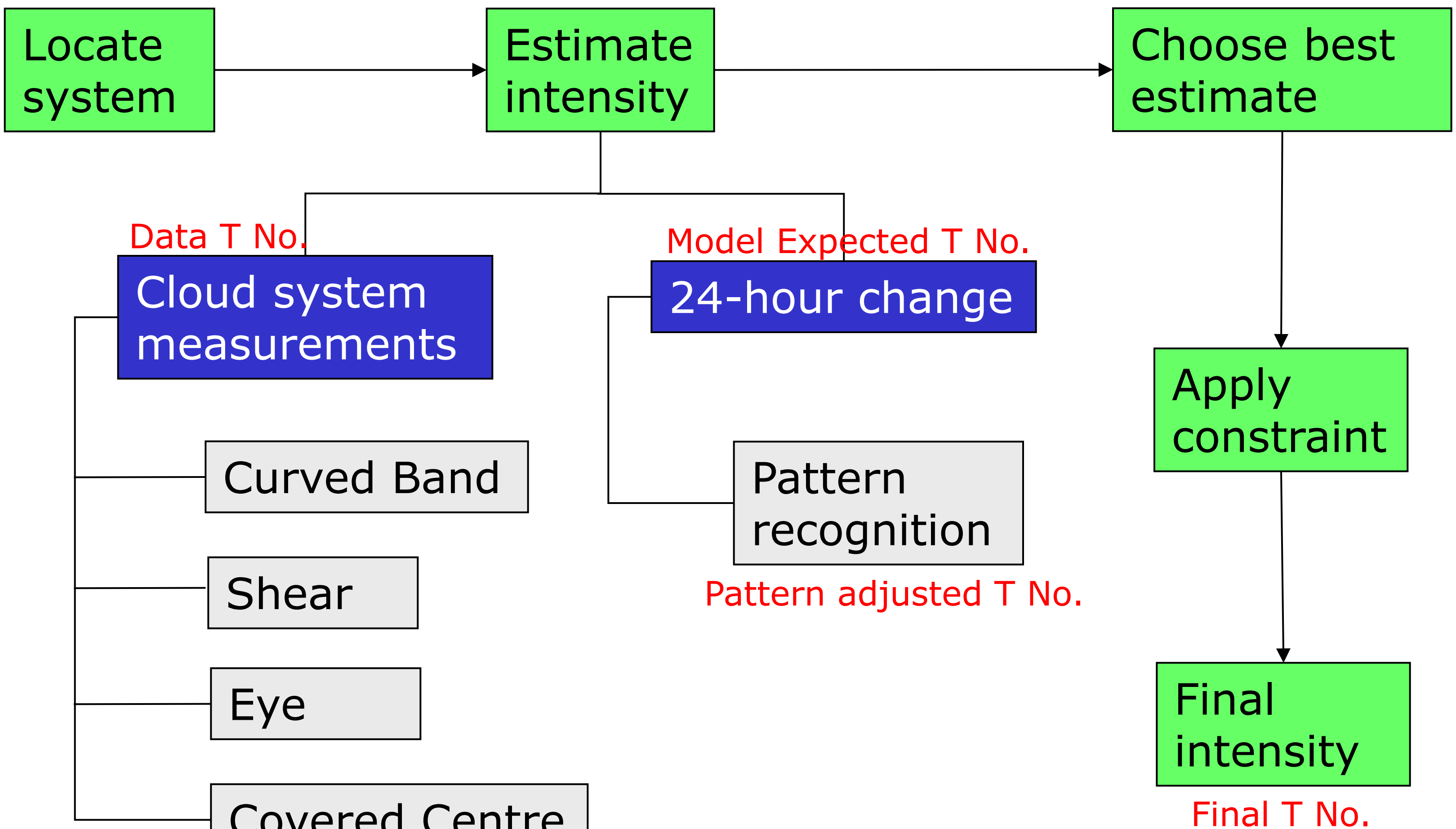
7. Use DT, MET, and PT to get Final T-Number (FT)

8. Apply FT constraints



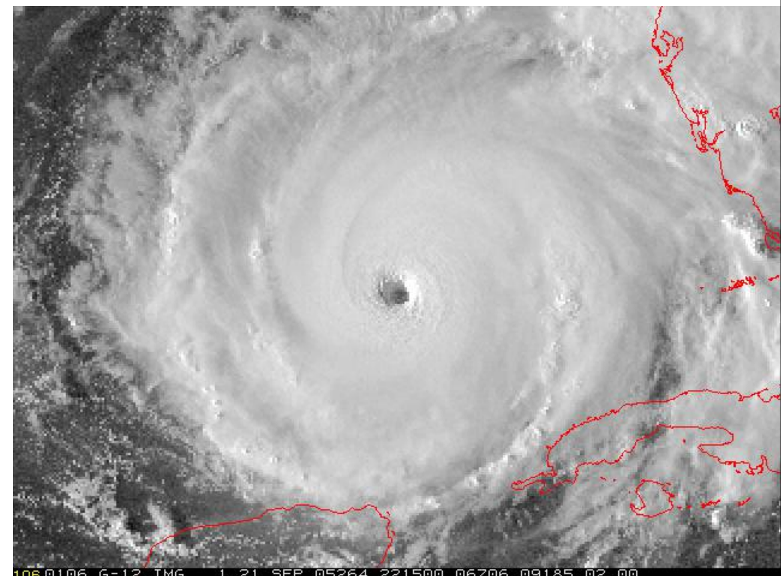
9. Determine Current Intensity (CI) **10. Forecast 24-h Intensity**

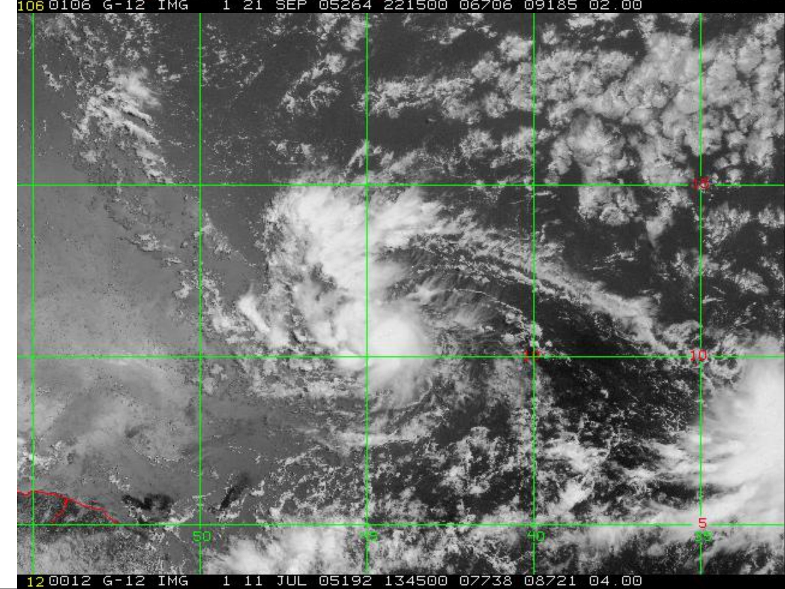
Key Analysis Steps



Step 1 - Locate the Cloud System Center

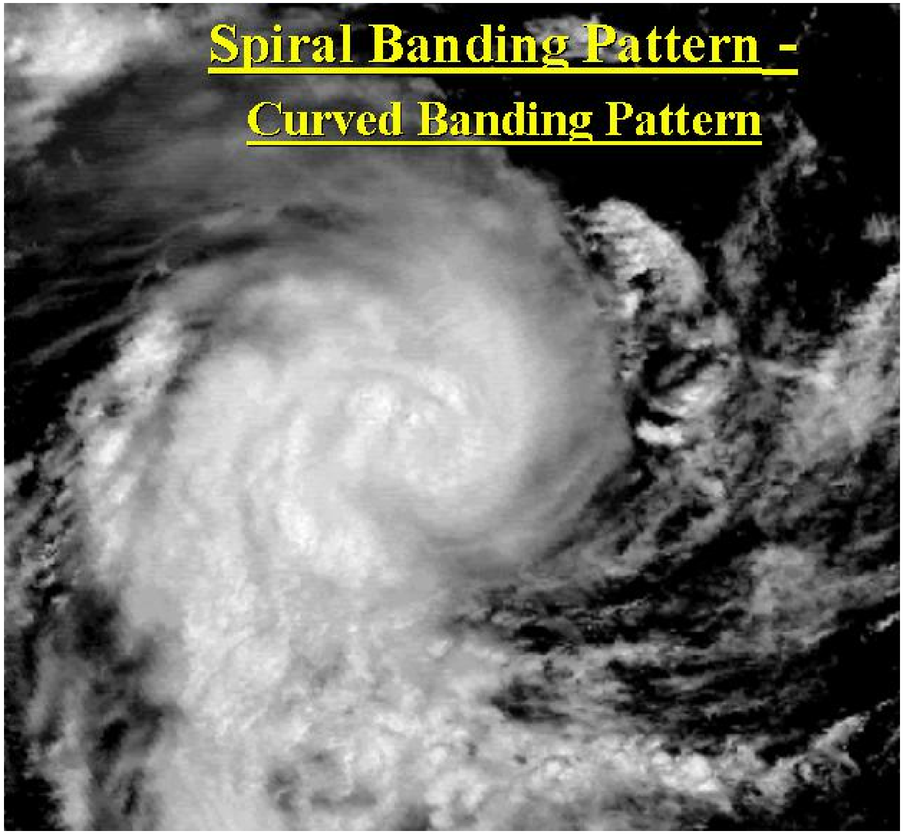
- **Locate the overall pattern center**
- **Look for small scale features**
- **Compare center location with forecast**
- **Compare center with previous pattern center**
- **Make final location adjustments**
- **Looking for lowest possible center in terms of altitude (Surface center if possible)**





Spiral Banding Curvature Fixes

- Draw Streamlines on the image.
- Place each streamline so the curve lies as close as possible to the low level cloud lines (LLCLS) and convective bands.
- Follow the streamlines to the center.



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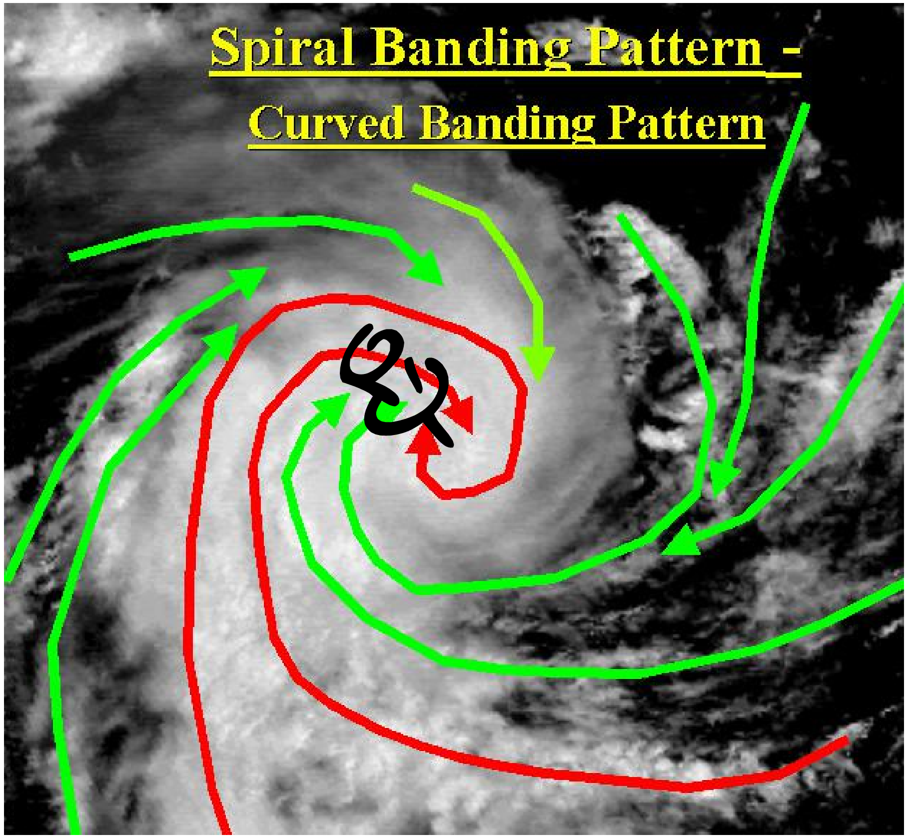
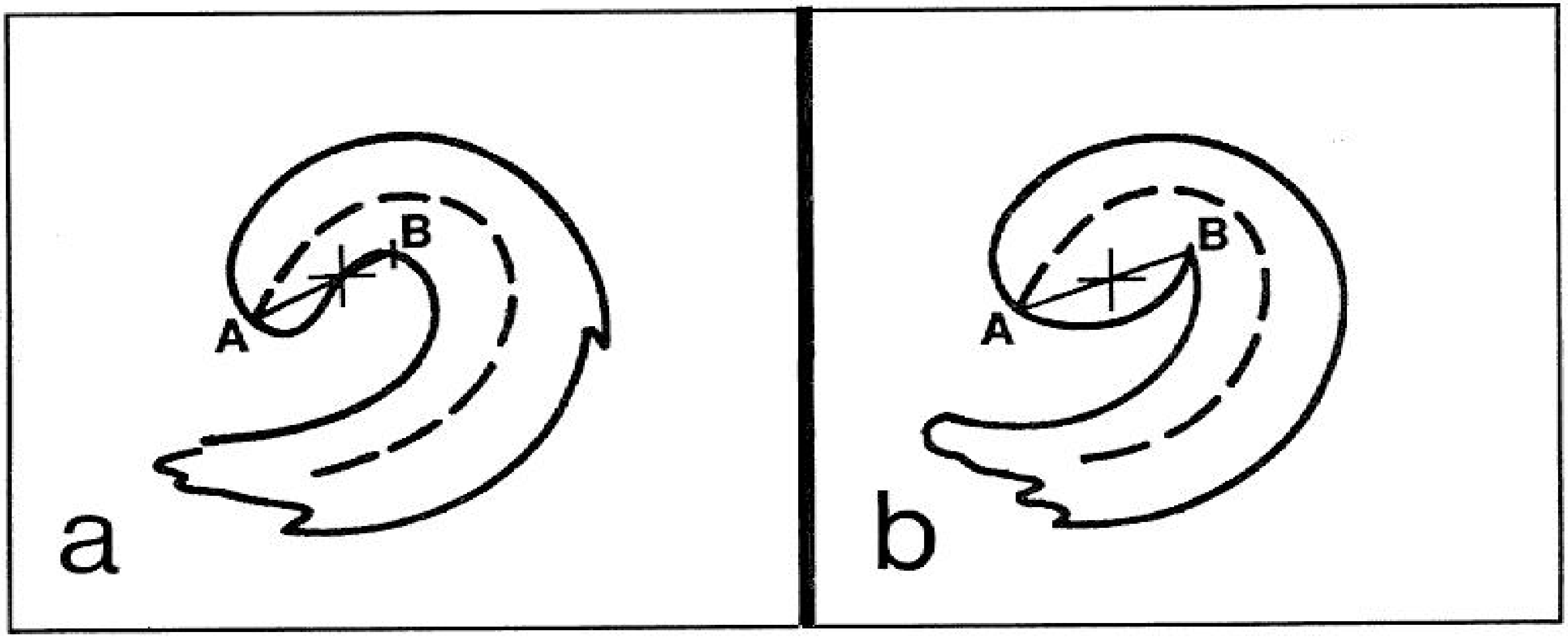


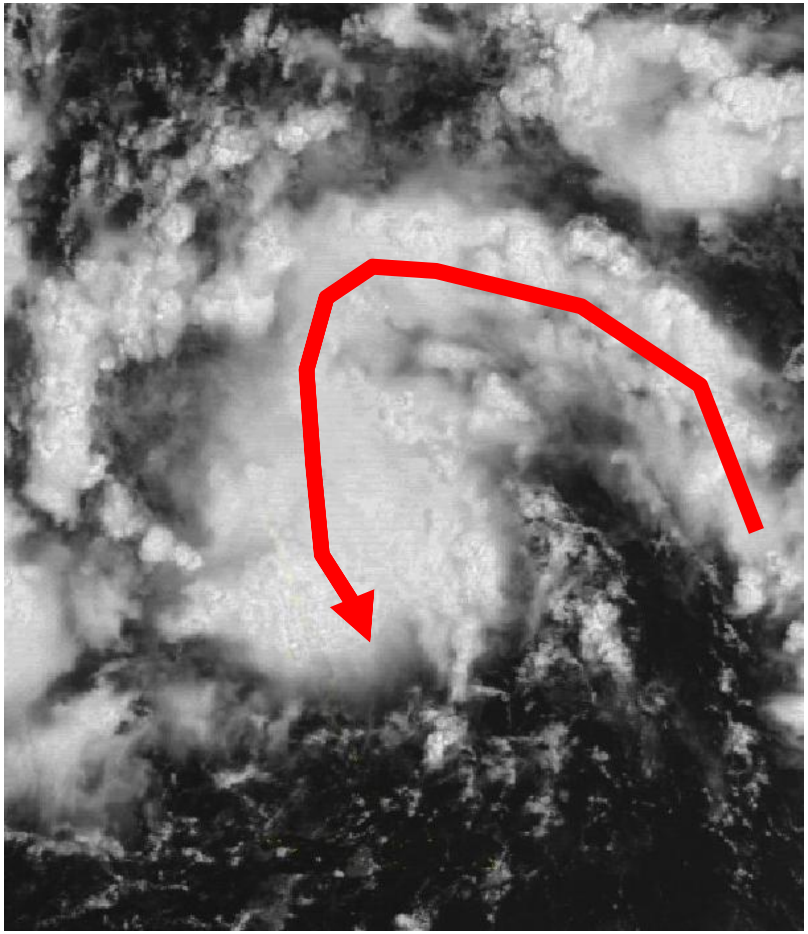
Expected CSC Positions for Curved Band Patterns



there are only one curved cloud band, and the axis is along the middle of the band. So we draws a line between the head of the comma and the most concave position of it(the tip of the wedge). The middle point of this line is the center of TC

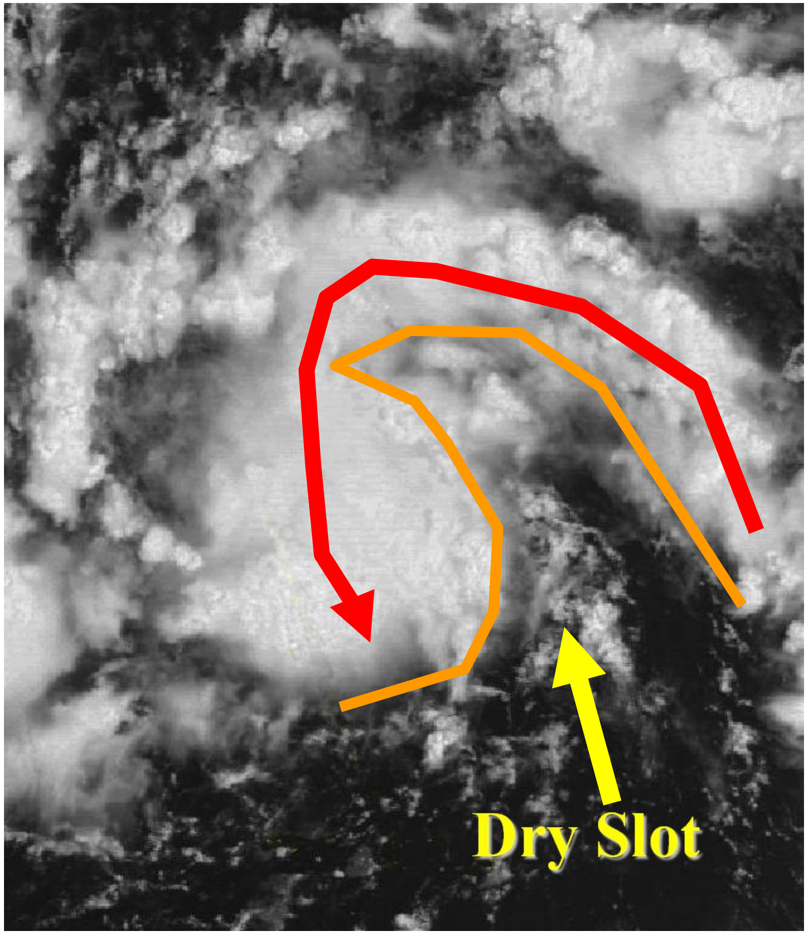
Cloud Minimum Wedge

- The center will be halfway along a line drawn from the tip of the wedge straight across the comma head



Cloud Minimum Wedge

- The center will be halfway along a line drawn from the tip of the wedge straight across the comma head



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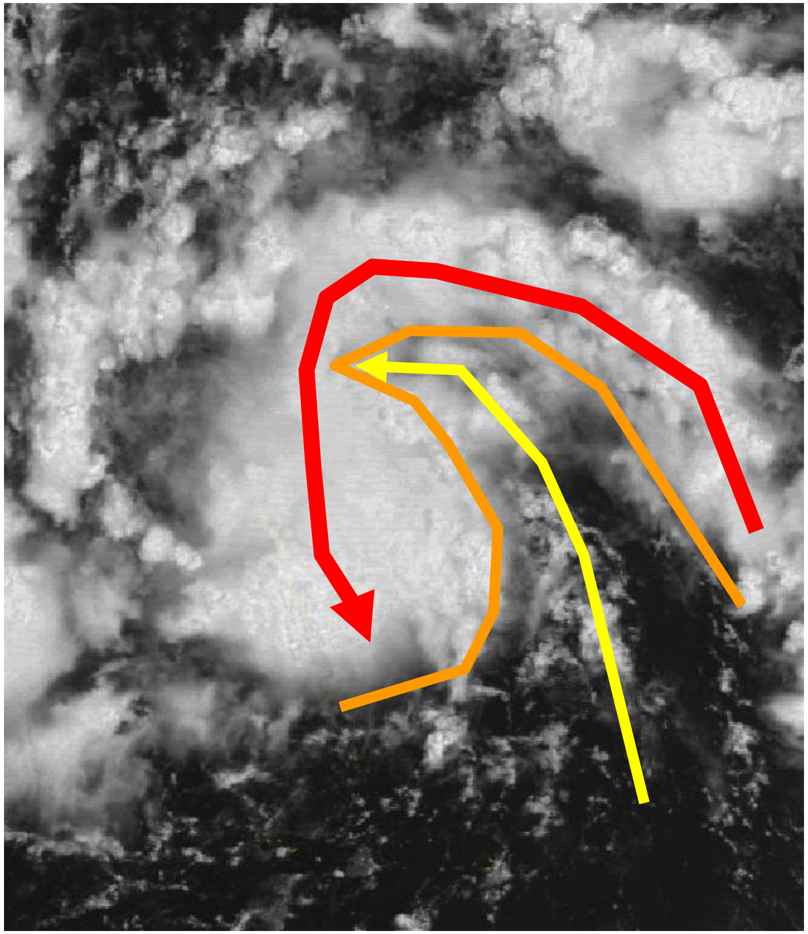

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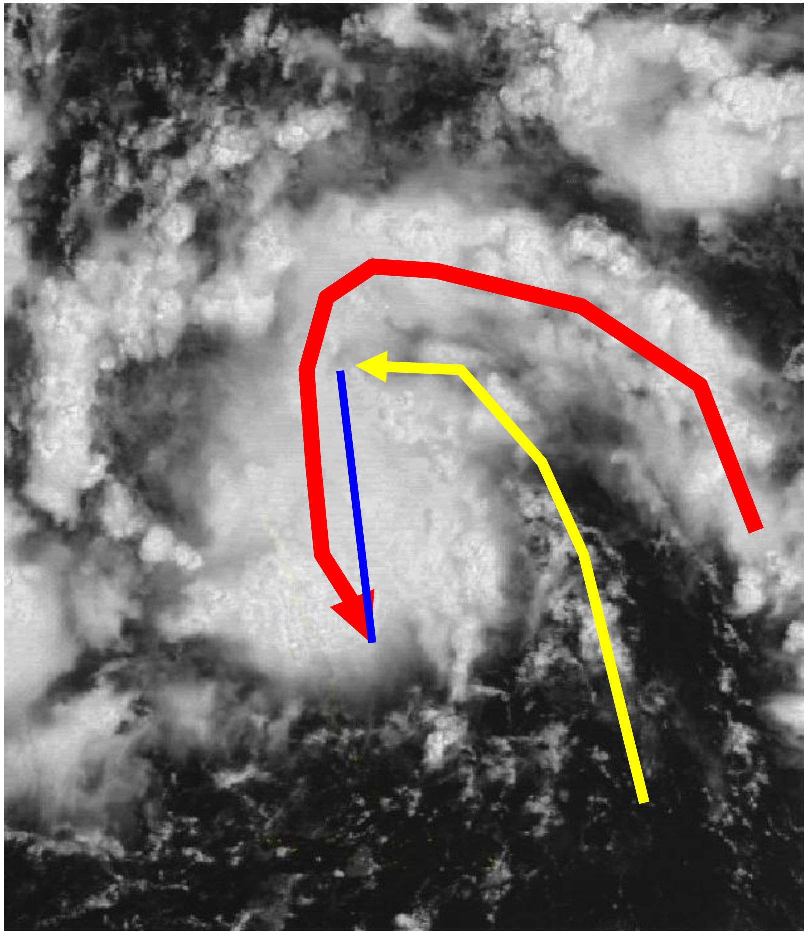

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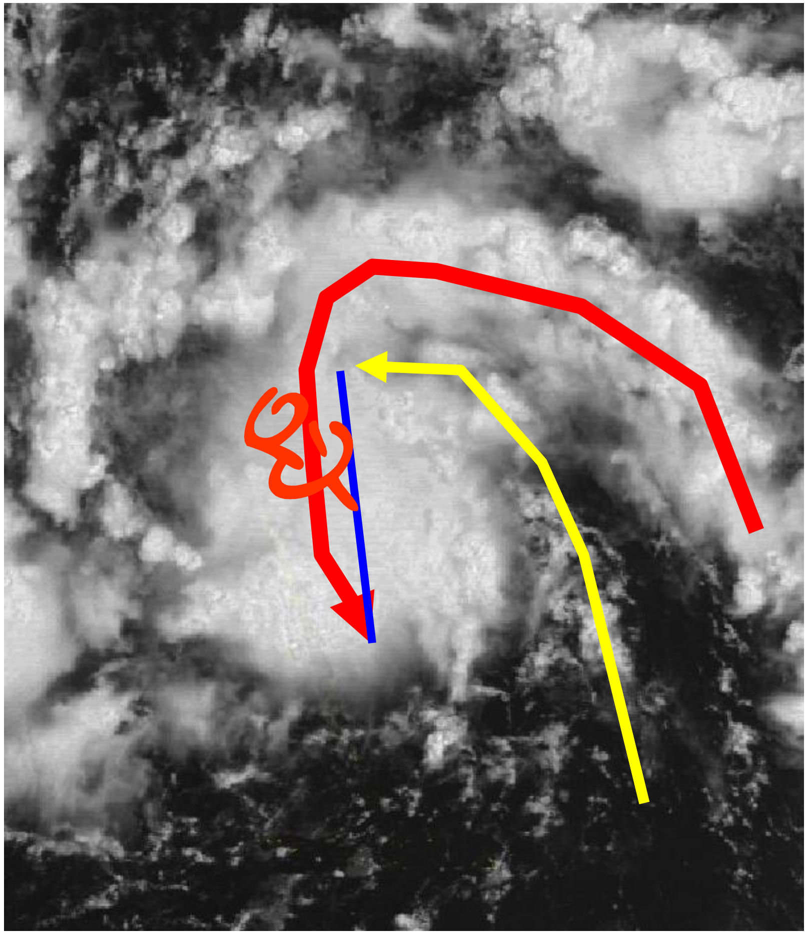

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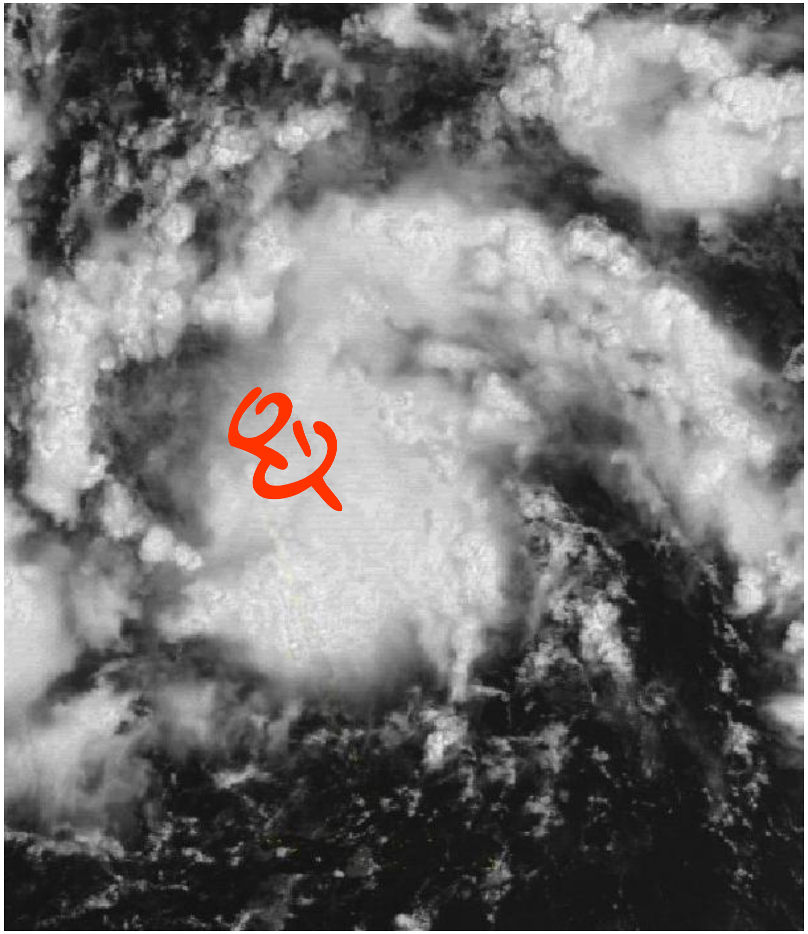
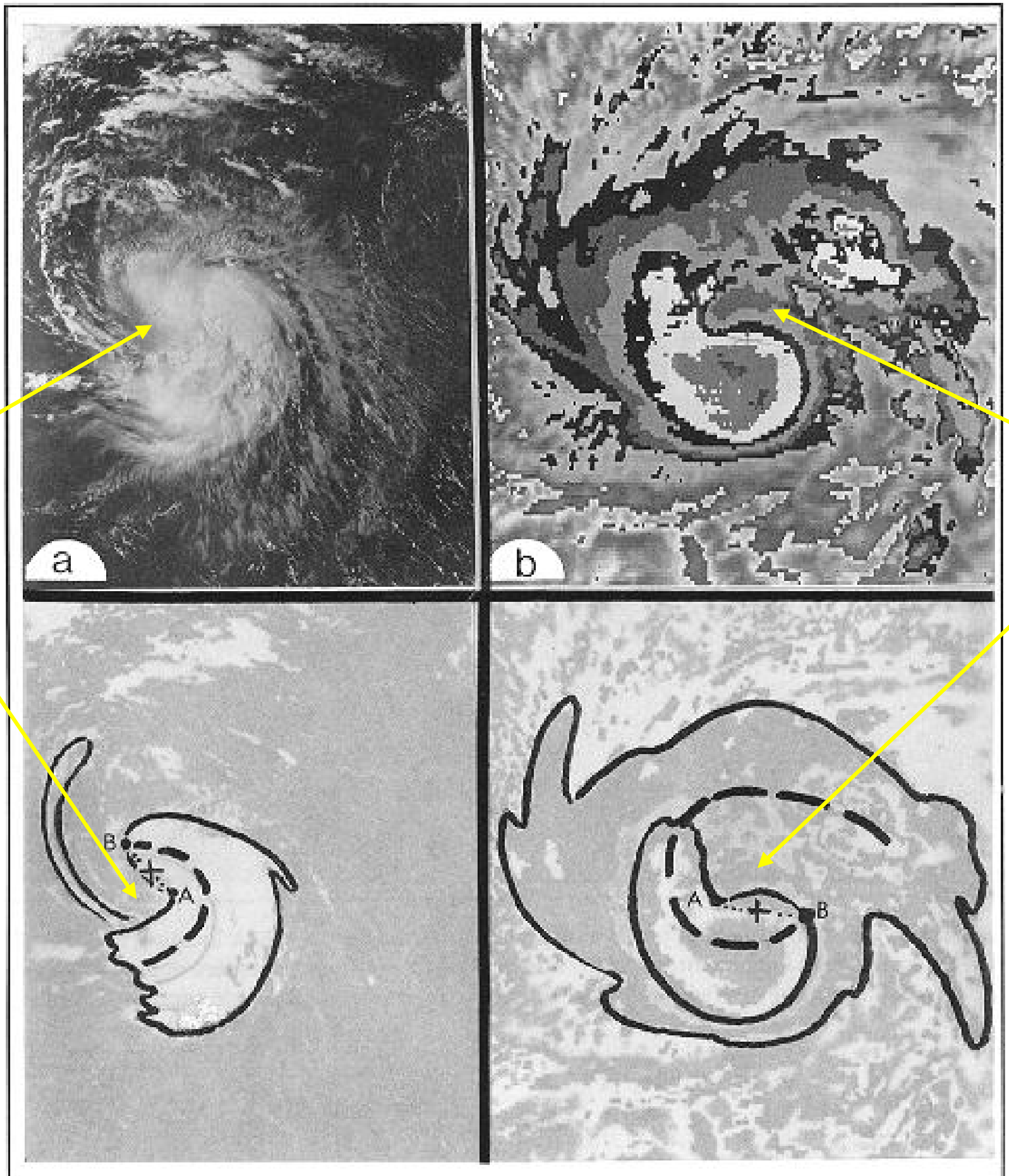


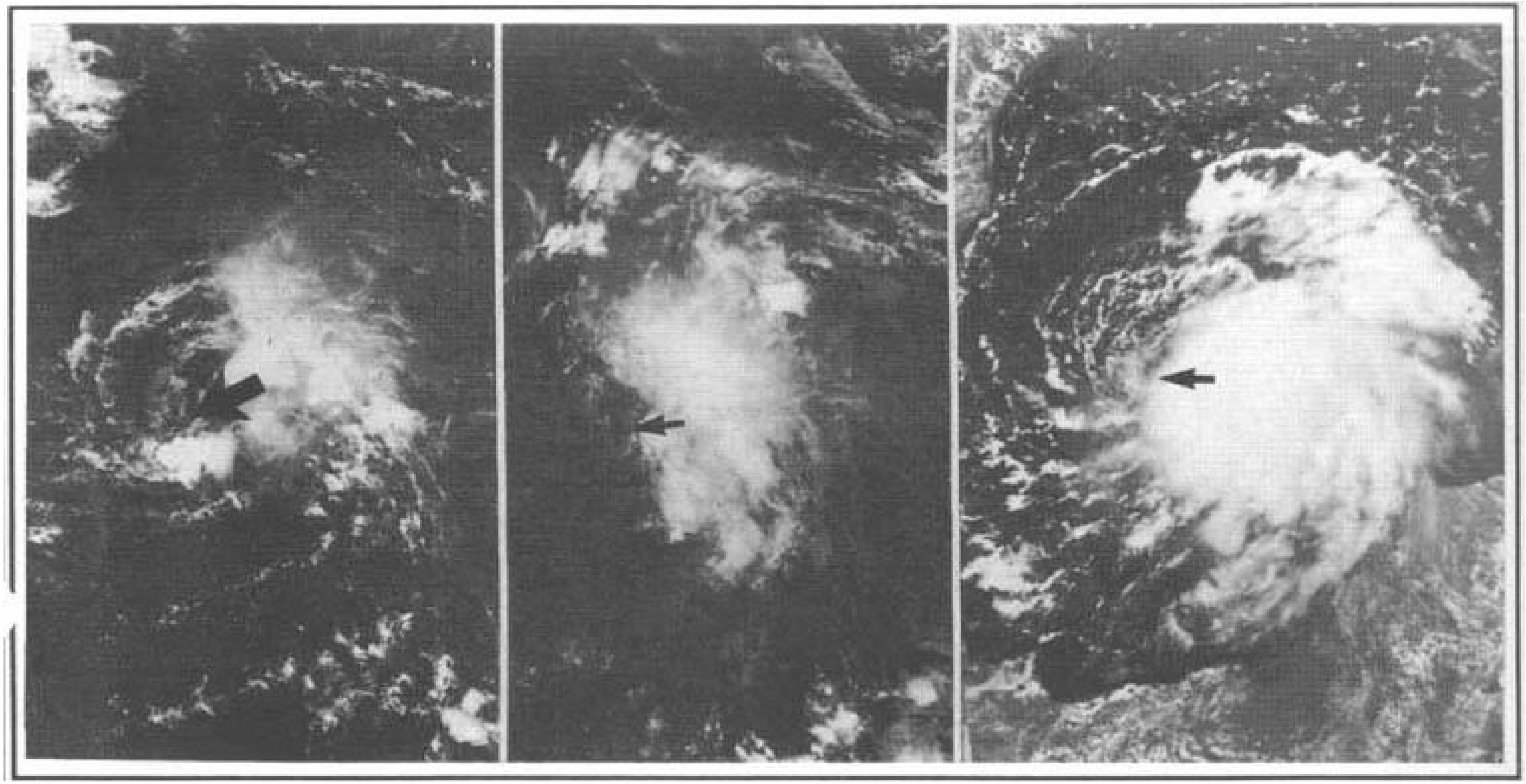
Curved Band Examples

Dry slot

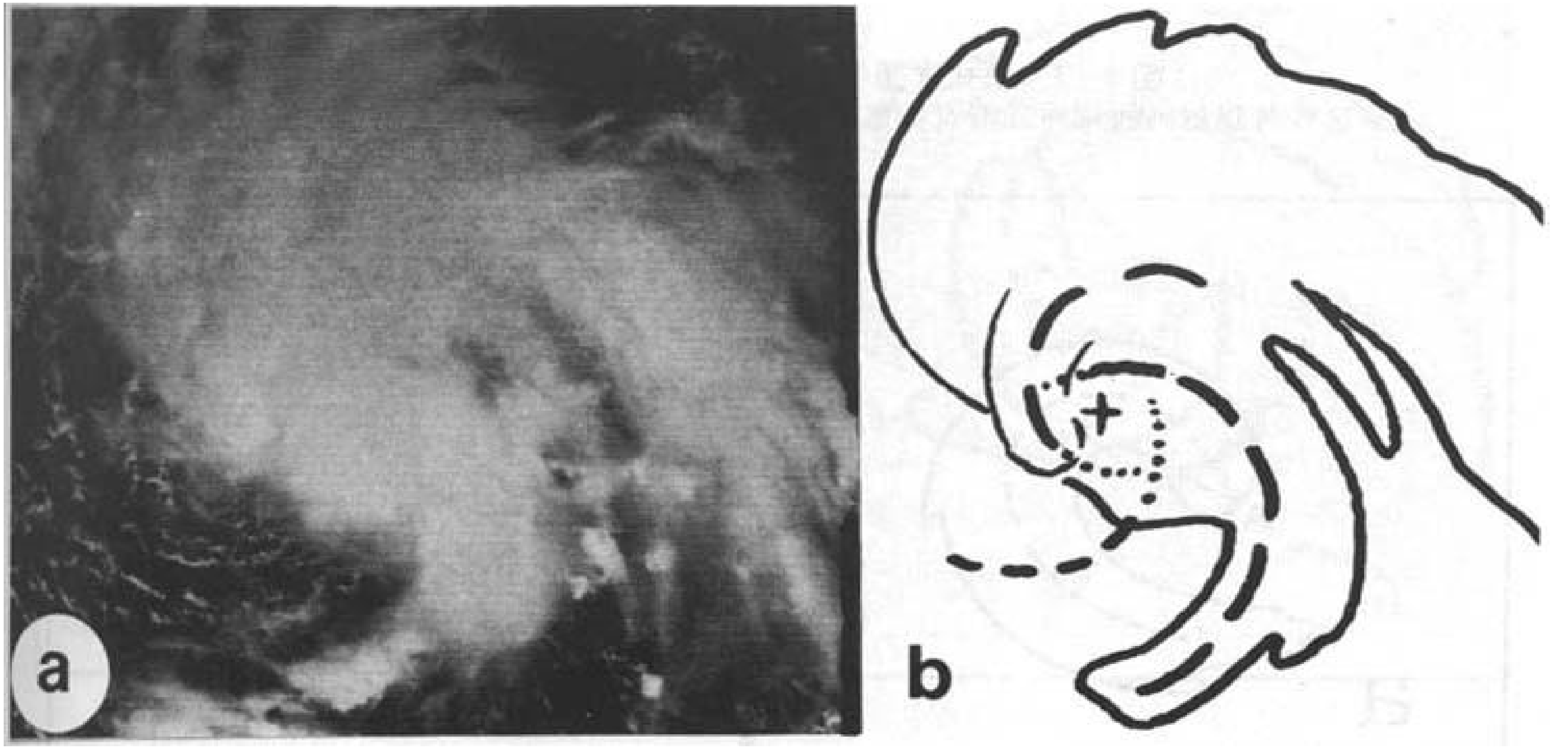


Dry slot

Shear Pattern（higher cloud is separated from low-level circulation ）



This type of cloud includes several curve cloud lines, generally, they form the center of curvature, which lie out of the dense overcast or nearby, as shown by the arrow .

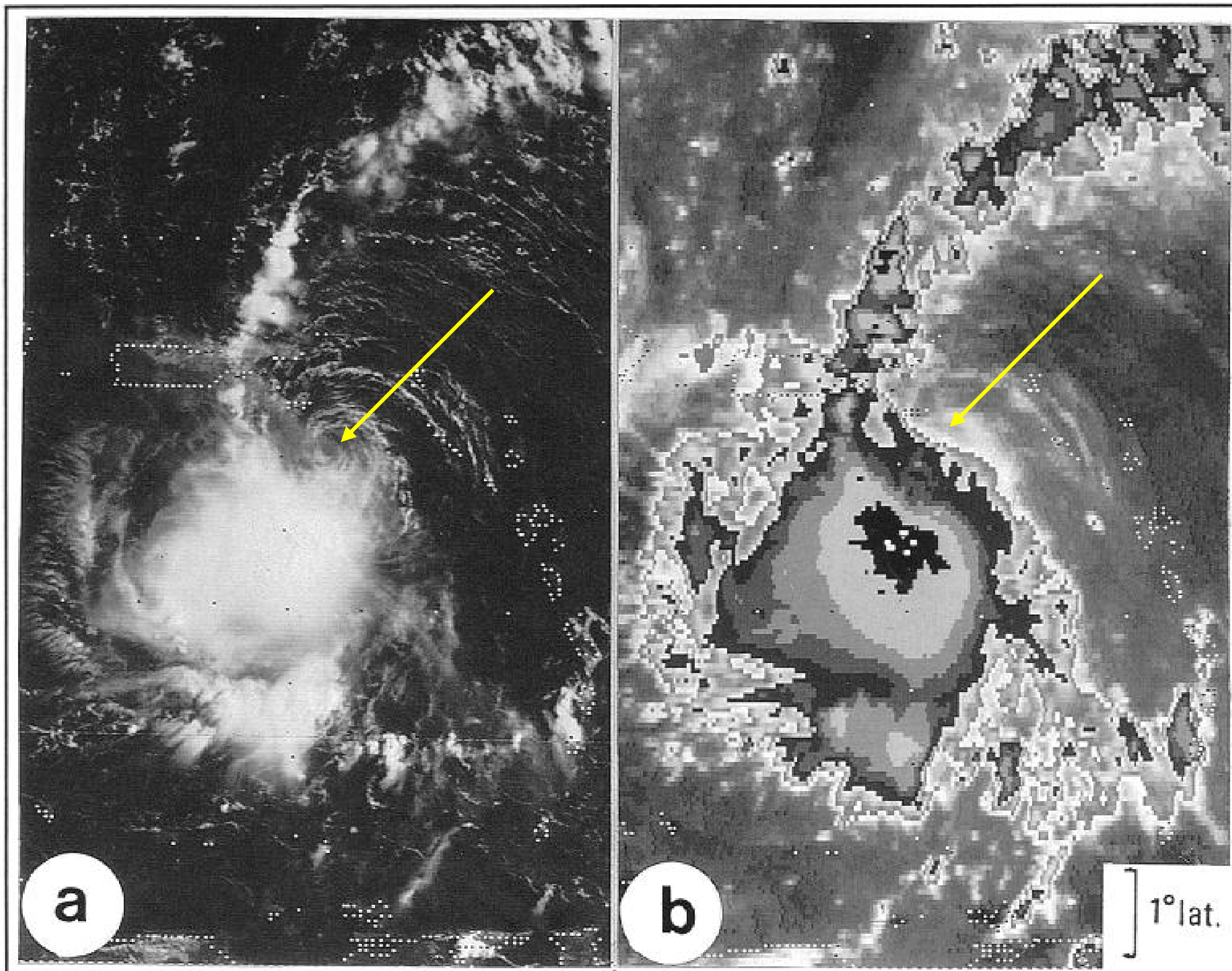


- Figure b is the sketch map of figure A, the broken lines are the axis of the brighten cloud bands,
- There are three bands, two wide bands and one thin band. the dot lines are the extend of the axis. The TC center lies in the area that the lines encircled.

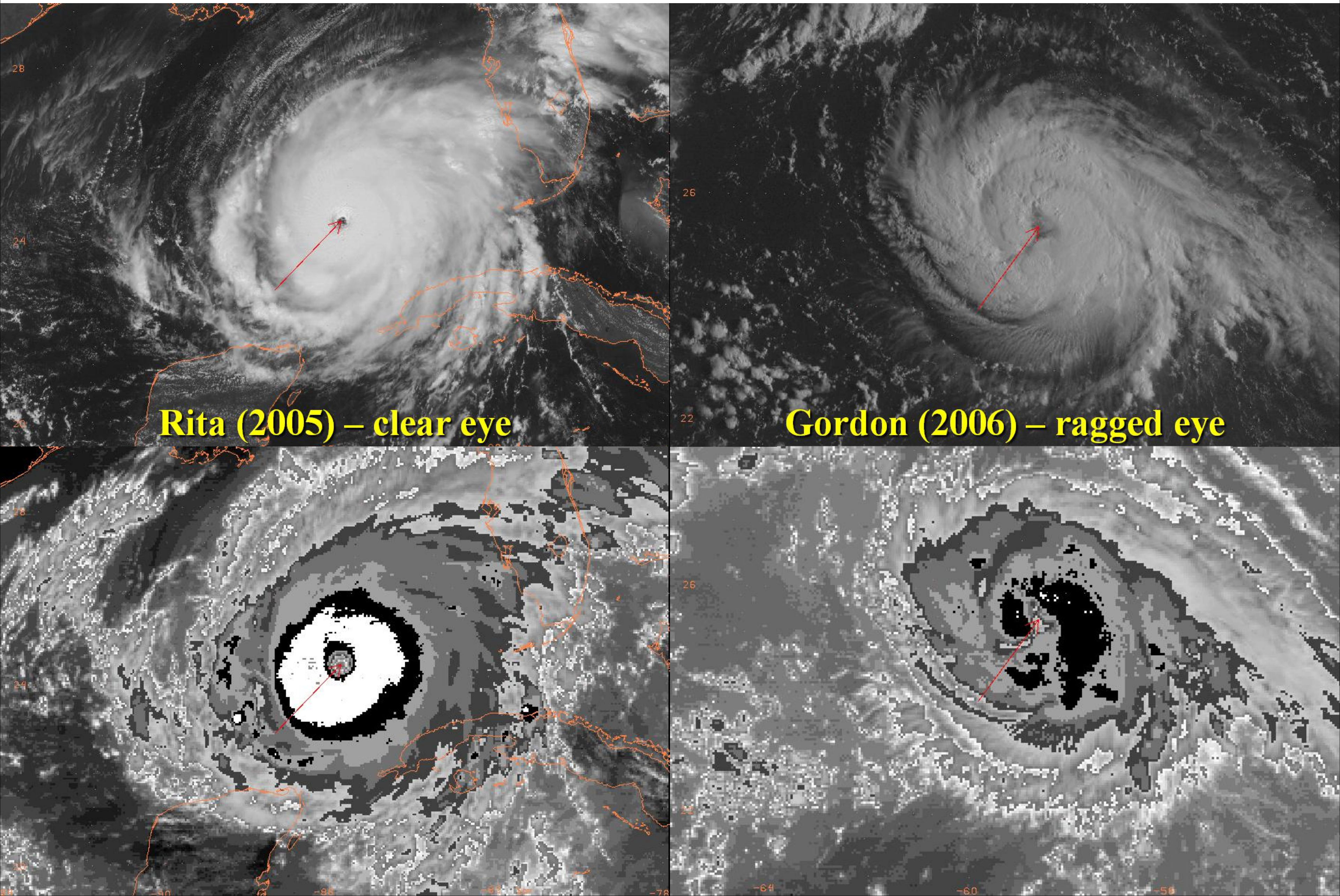
Shear Example

For shear

patterns, a good first guess for the CSC location is the up-shear side of the strongest convection

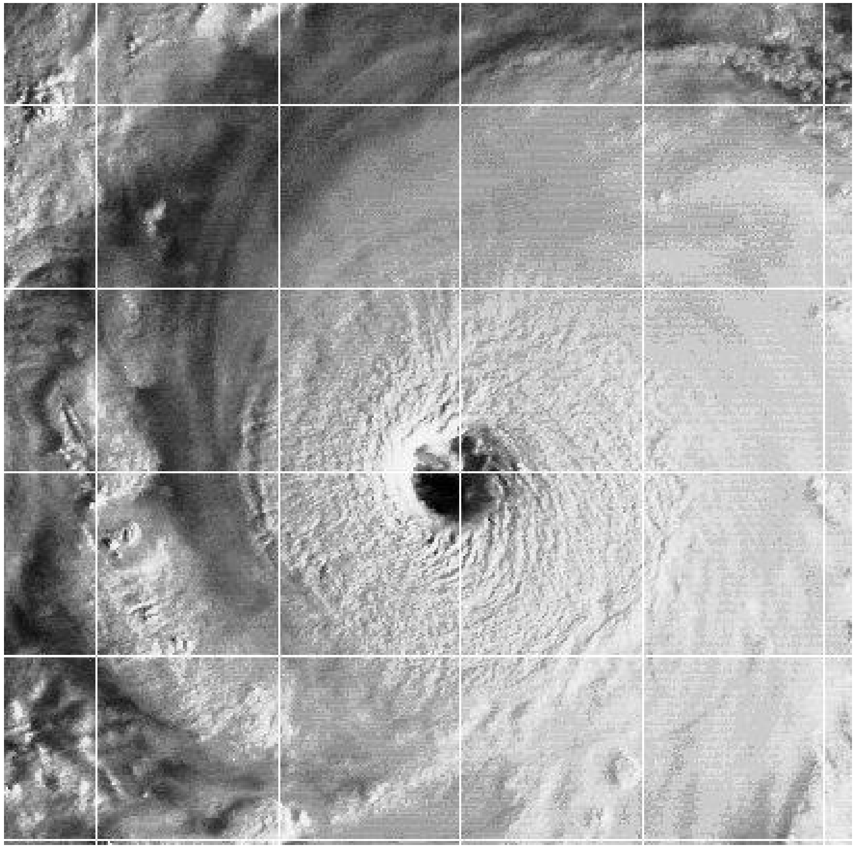


Eye Pattern Examples



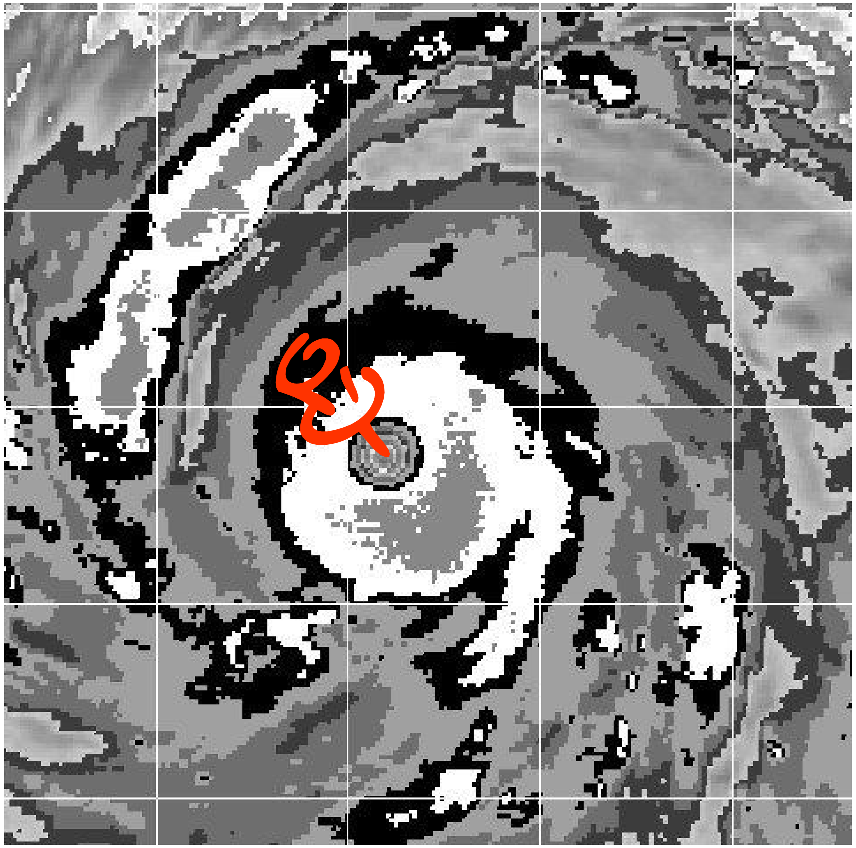
Eye Fixes Visual (VIS)

1. Dark cloud free spot
2. Shadowy spot for cloud filled eye



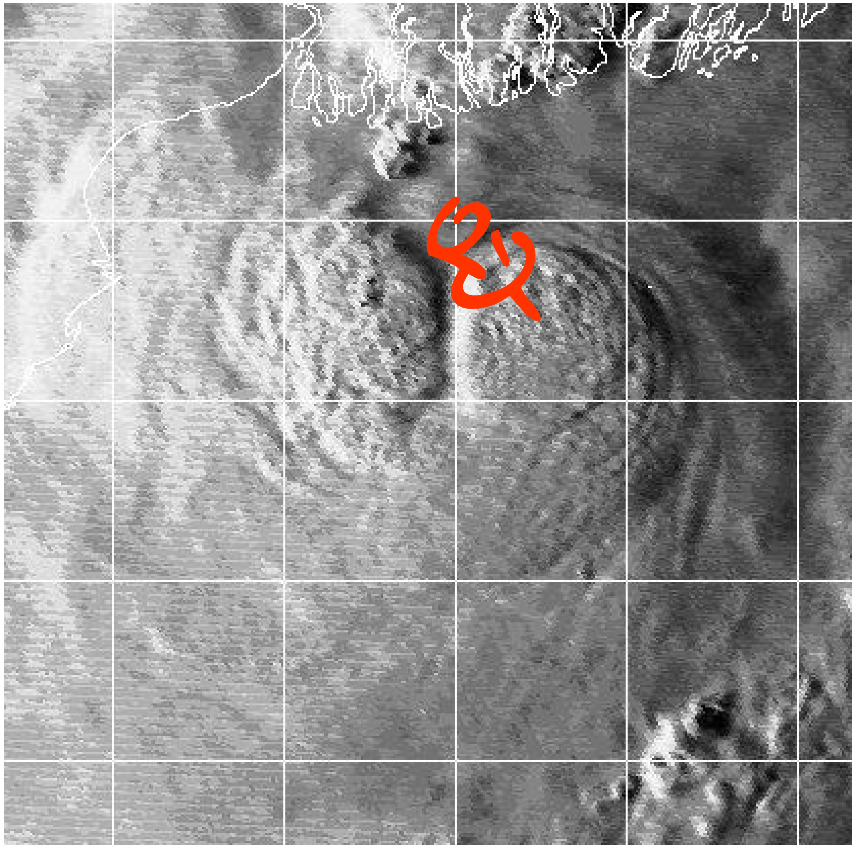
Eye Fixes Infrared (IR)

- **IR Warm spot**
  - Use **warmest** spot.
  - Eye boundary (eye wall) defined by the tightest temperature gradient



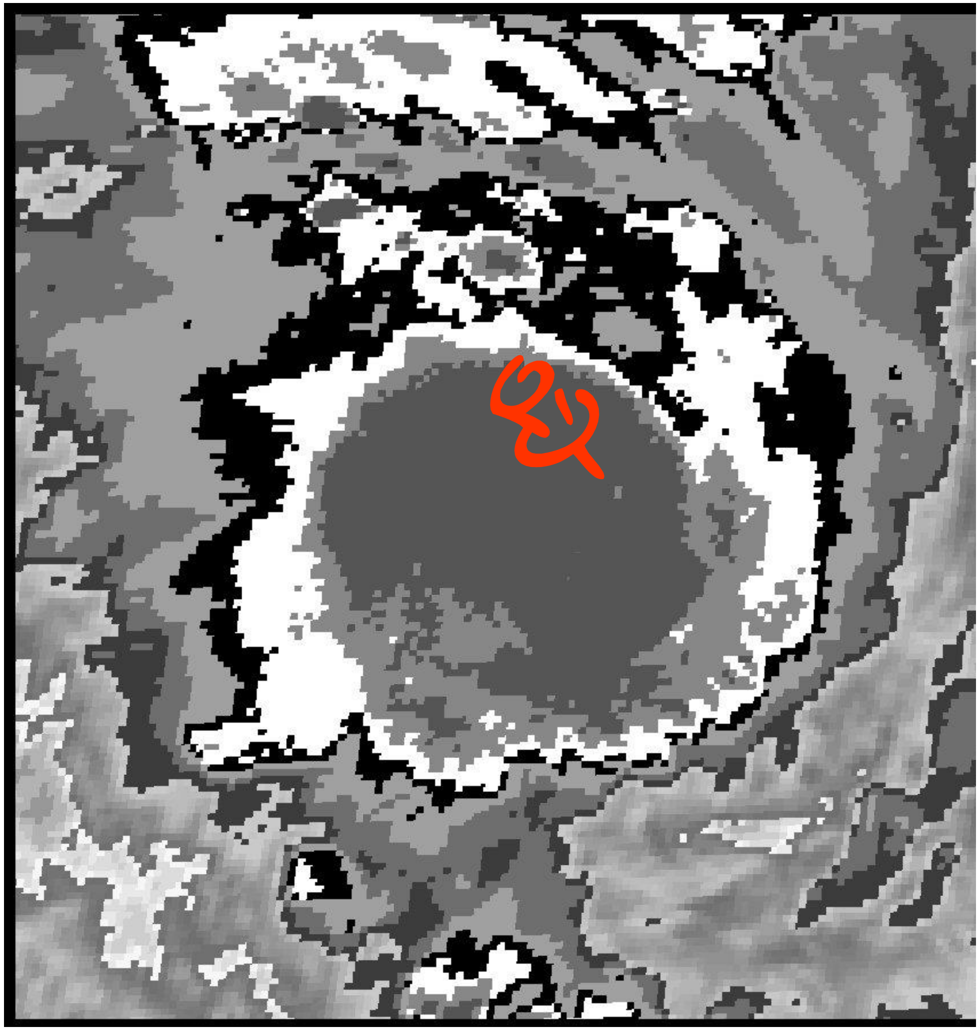
CDO Center Examples

- VIS only
- Look for low level cloud lines to extrapolate underneath convection
- Look for overshooting cloud tops - bias Low Level Circulation Centre （LLCC） toward tallest cloud tops!

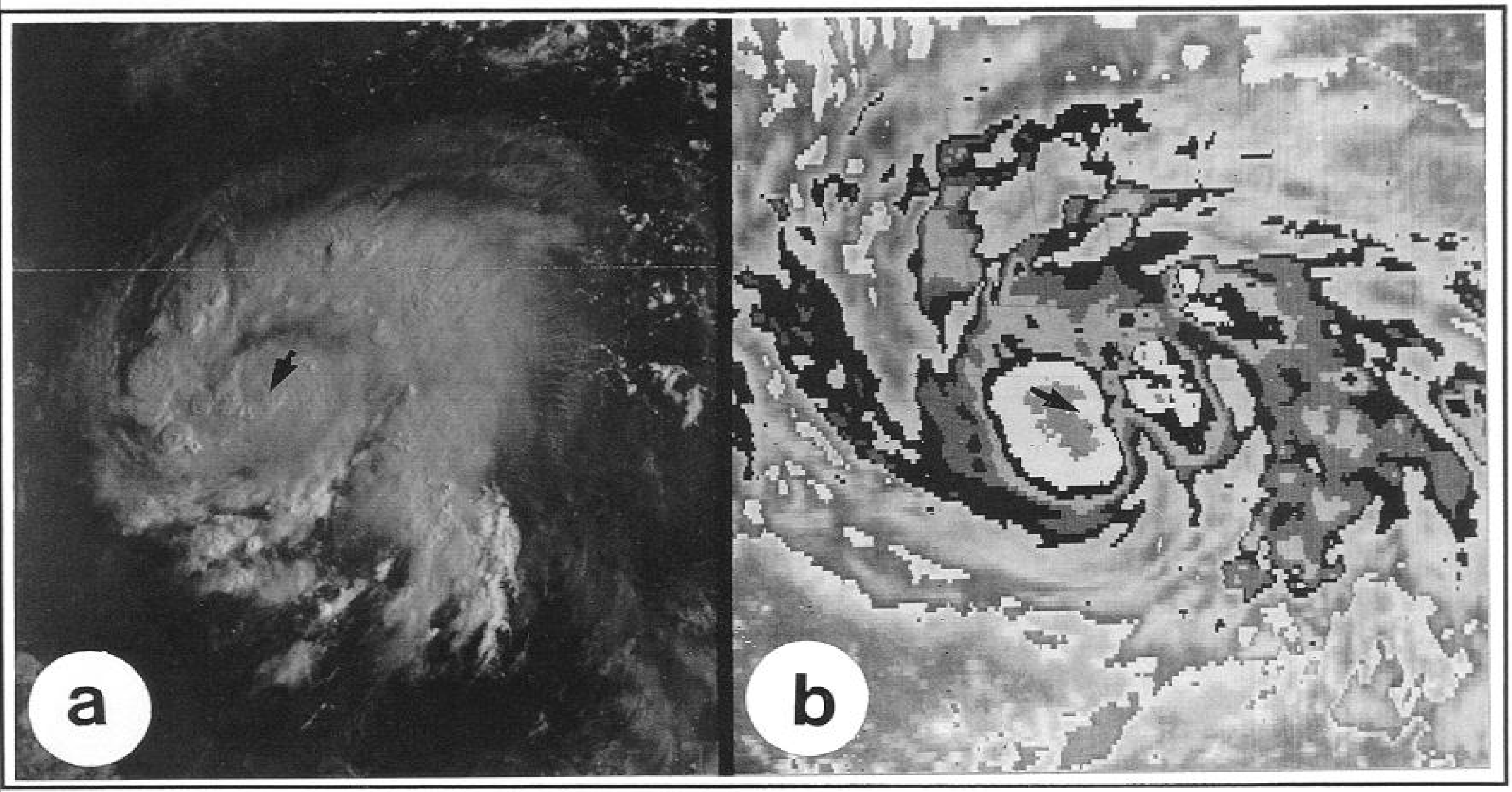


Embedded Center Examples

- Look for a warm spot
- Look toward the edge with the tightest temperature gradient
- Don't forget continuity with past positions

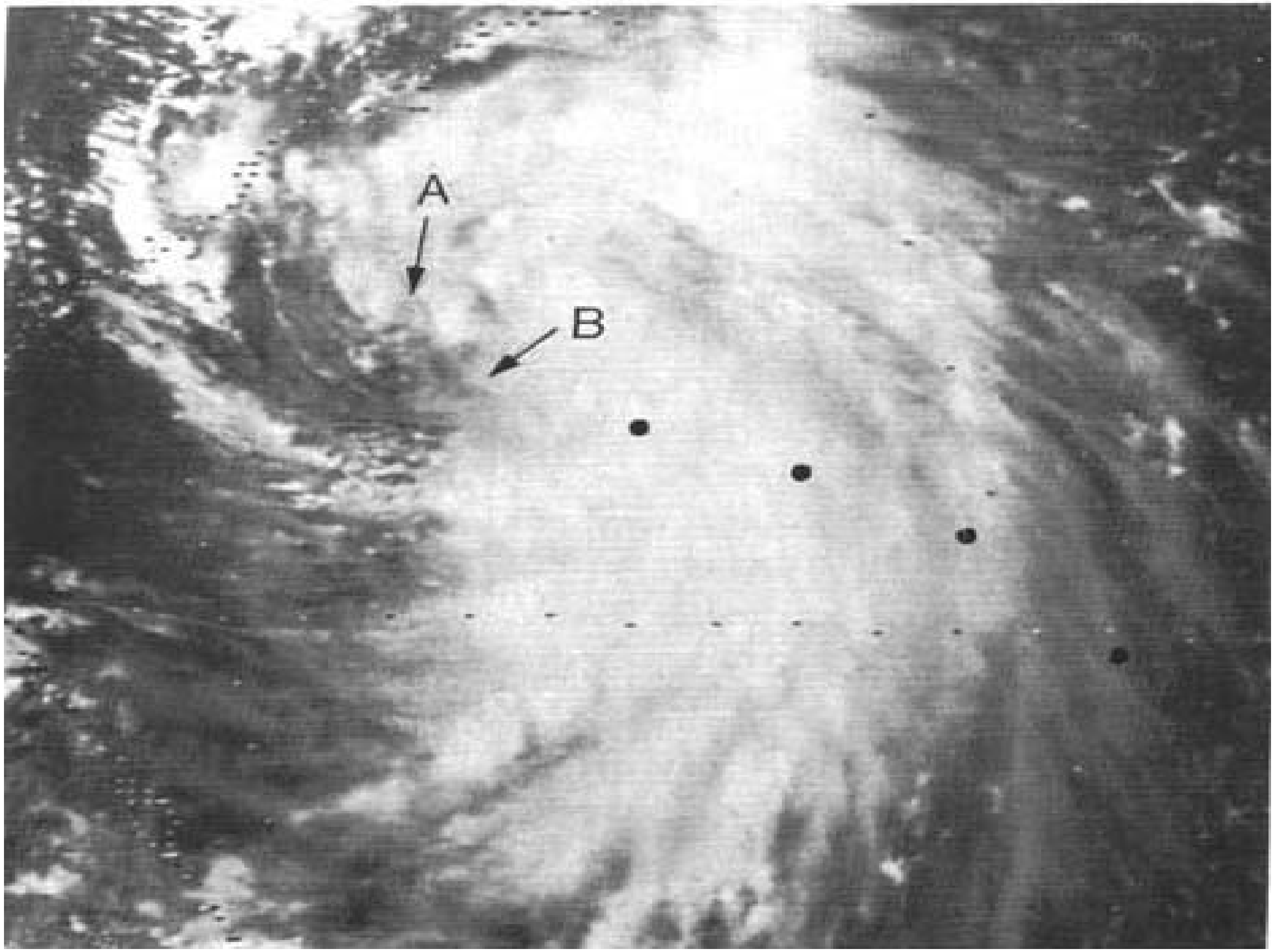


CDO / Embedded Center Examples (VIS / EIR)



There are two examples that using high-level cloud to determine the center of TC. In figure A, we can see that there is a convective cloud top in CDO, the center is in this area. In figure b, there is a warmer hole in the CDO. When these features appear near the center, the center will be located in these features and nearby area. As the arrow point.

Comparing the position between located and forecasted



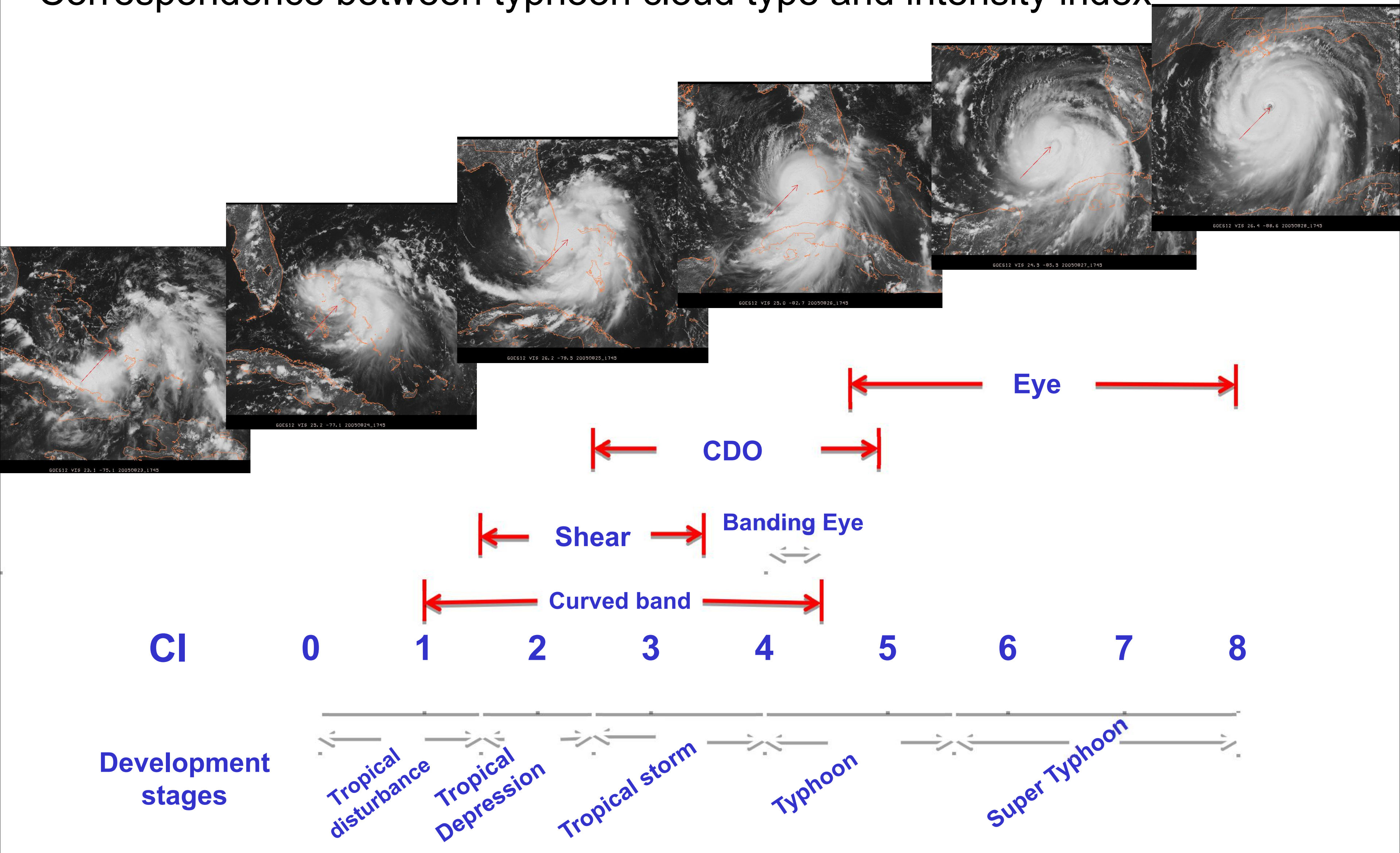
After we get a center position, we should compare it with the forecasted position according to the historic path. In this example, the first position located in A, but the forecasted position is in B, So we must check the position again and get the correctional position.

The factors affecting the accuracy of center location

- Degree of storm cloud organization
- Image grid placement
- Satellite type and resolution
- Satellite viewing angle
- Subjective in the interpretation of cloud pattern organization

Step 2 - Analysis of the TC intensity

Correspondence between typhoon cloud type and intensity index



Dvorak Output

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

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

Determination of typhoon intensity based on cloud image

Central Feature

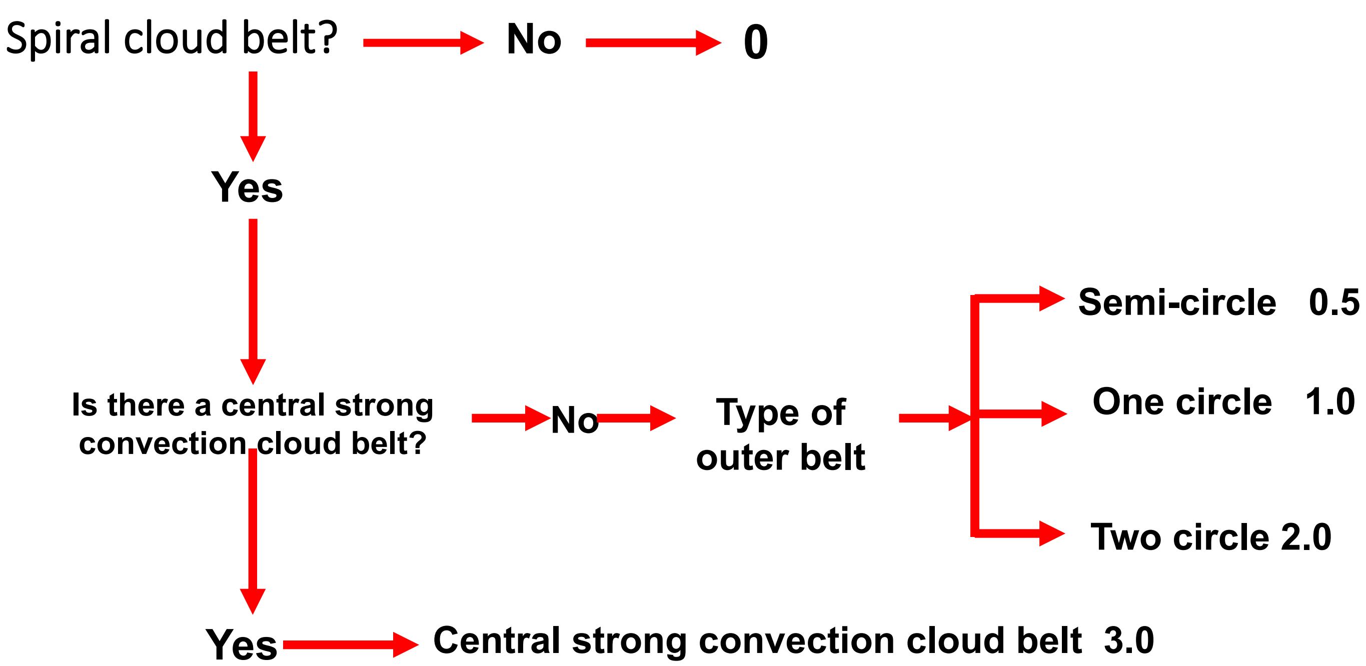
- **Eye?**
  - **No** → **The relationship between dense overcast and low lever center**
    - **Low level center is outside the dense overcast 0.5**
    - **Low level center is at the edge of dense overcast 1.0**
    - **Low level center is in the dense overcast 1.5**
  - **Yes** → **Type of eye**
    - **Irregular eye 2.0**
    - **Big round eye 2.5**
    - **Small round eye**
      - **No clear 3.0**
      - **Clear 4.0**

Central dense cloud area size

Central dense cloud area size → **(a**verage distance from east to west+ average distance from south to north**)/2**

Determination of typhoon intensity based on cloud image

Banding feature



Typhoon total strength index**(CI)= Central Feature + Central dense cloud area size + Banding feature**

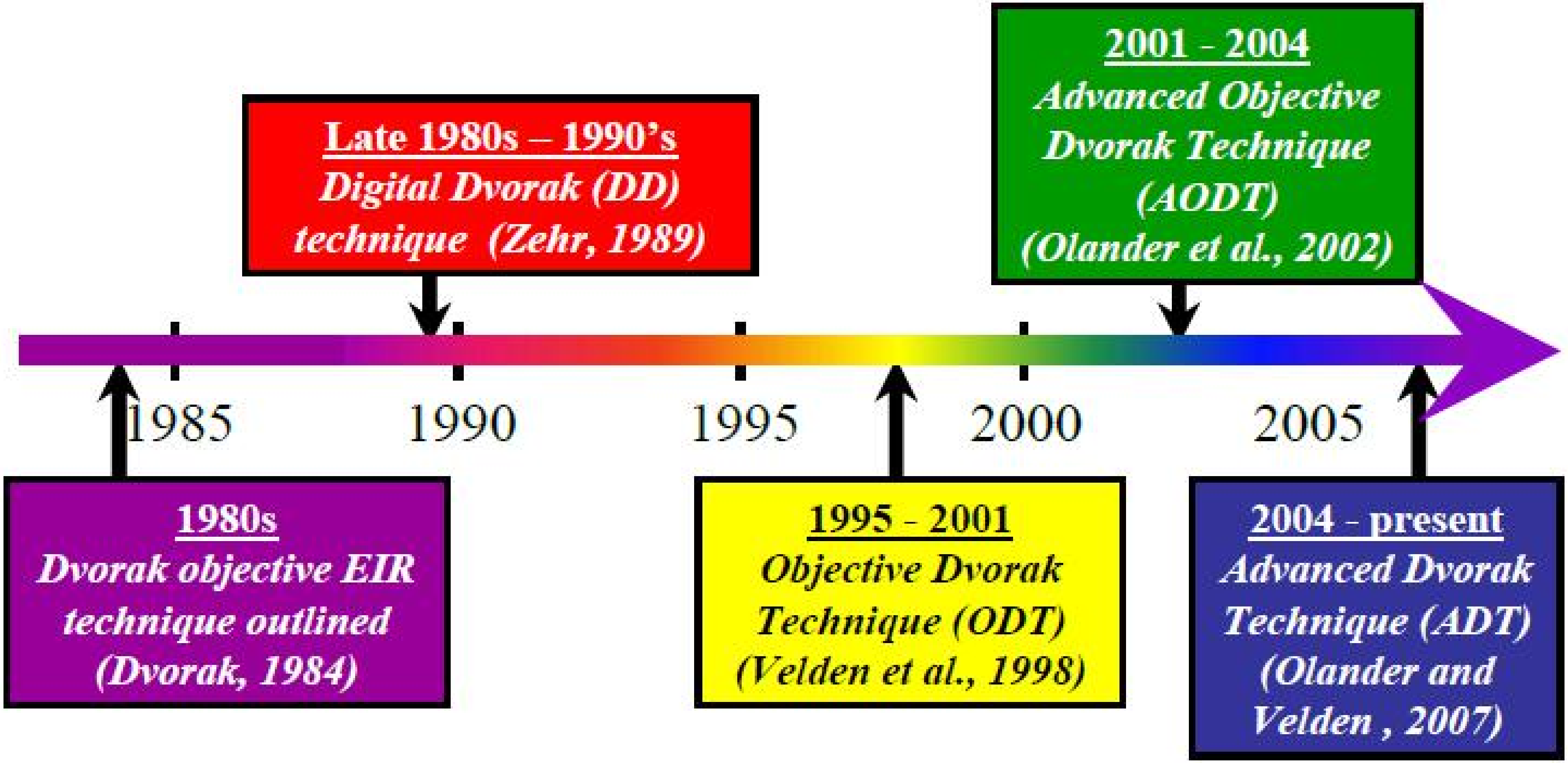
Dvorak Analysis of TC Intensity

- Strengths
  - Consistent, relatively simple approach to a difficult task
  - Time proven, the primary technique for more than 30 years
  - Valid for all geographic regions
  - Patterns based on cloud response to vorticity
  - Better validation and confidence for the more intense storms
- Weaknesses
  - Some aspects are too subjective
  - "spin down" times are too uniform
  - poor intensity estimates of very small storms "midgets" at night
  - Does not account for subtropical or extratropical transition
  - Does not compensate for large translation speeds (left to the forecaster)
  - Training and experience are very important because of the subjective nature of the method.

Limits of Dvorak technique

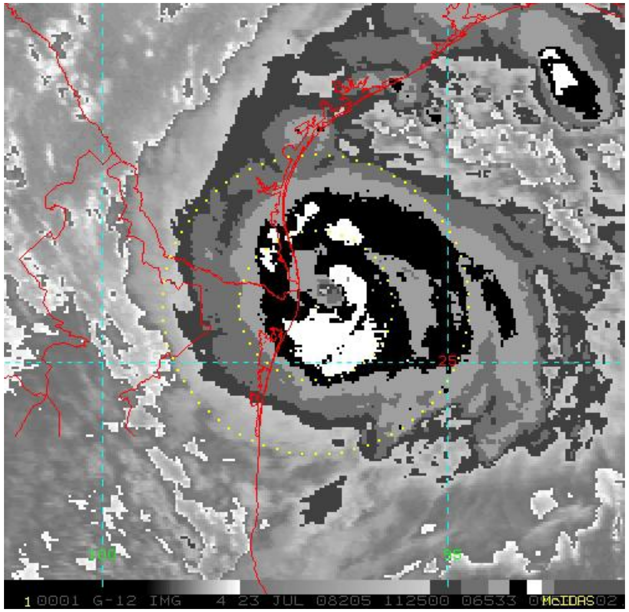
- Dvorak technique is a measurement of cloud shape rather than a direct observation of TC wind field, atmospheric pressure or other meteorological elements.
- Methods based on subjective analysis and interpretation, it is easy to produce analytical errors.
- Restricted by the spatial resolution of satellite cloud images, the error of Dvorak technique in estimating some small-scale tropical cyclones will increase.
- Dvorak technique is mainly used for regular tropical cyclones in the ocean. The accuracy of Dvorak technique will be significantly reduced after landfall.
- For fast moving tropical cyclones (speed >15 nautical miles), the Dvorak technology bias is expected to increase.

Objective Technique Development Timeline



Objective **Dvorak** Technique Development

- DD – Digital Dvorak
  （Zehr, 1989）
  - ✓ Attempt to use EIR Dvorak Technique to estimate typhoon intensity subjectively.
- ODT – Dvorak Objective Technique
  （1995 – 2001，Velden et al., 1998）
  - ✓ Attempt to automate EIR Dvorak Technique
  - ✓ Only for strong and greater intensities
  - ✓ Manual storm center
- AODT – Advanced Objective Dvorak Technique（2001 – 2004，Olander et al., 2002））
  - ✓ Developed a method to automate the positioning of typoon

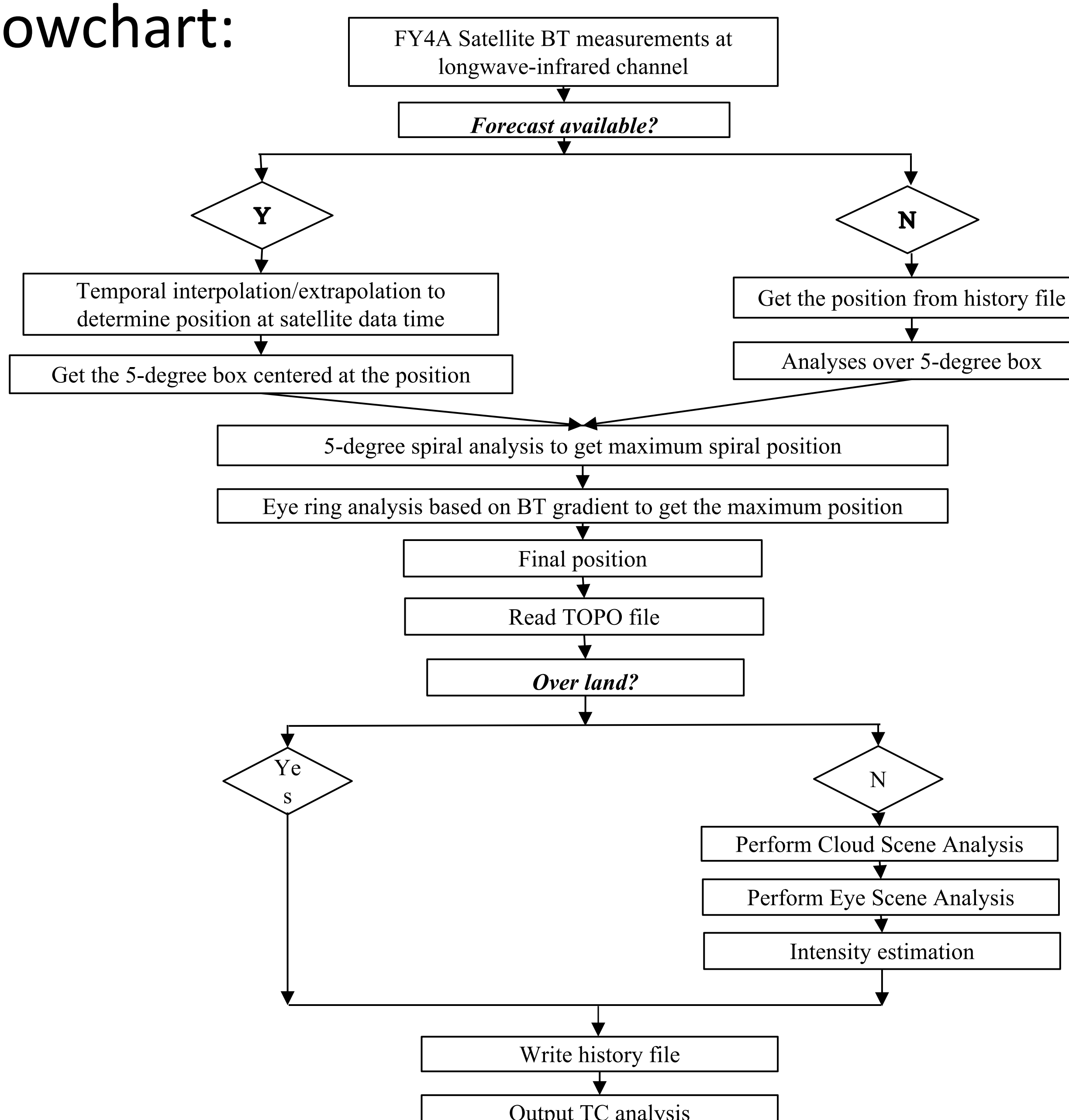


ADT – advanced Dvorak technique

（2004 - present，Olander and Velden, 2007）

- ✓ Totally automate determine the typhoon center and intensity.
- ✓ Developed the method of intensity estimation.
- ✓ The accuracy of intensity estimation is better than subjective Dvorak technique.

Flowchart:



ADT – advanced Dvorak technique

The typhoon positioning method:

- Step 1: The interpolation of TC center from short-term forecast is used as the first guess.
- Step 2: Matching a digital image of brightness temperatures with a spiral pattern is accomplished by calculating the cross product between the image gradient and a spiral shaped unit vector field.
  - The formula for the spiral vector field is as follows:

$$\boldsymbol{S}_i(\emptyset, \theta) = \frac{\alpha x_i \pm y_i}{[(1+\alpha^2)(x_i^2+y_i^2)]^{0.5}}\hat{x} + \frac{\alpha y_{i\mp} x_i}{[(1+\alpha^2)(x_i^2+y_i^2)]^{0.5}}\hat{y}$$

  - $(\emptyset, \theta)$ are (longitude, latitude) in the spiral score field;
  - $\boldsymbol{S}$ is the log-5 spiral vector field;
  - α is the inclination of the spiral vector field in radians;
  - $\pm$ means "+" in the Northern Hemisphere and "-" in the Southern Hemisphere, and $\mp$ means the opposite.
  - $\hat{x}, \hat{y}$ are the unit vectors for north and east, respectively;
  - x_i, y_i are offset distances in the $\hat{x}, \hat{y}$ directions, respectively, where x_i is normalized to be approximately equal in spacing to y_i

ADT – advanced Dvorak technique

The typhoon positioning method:

- The spiral centering is performed by application of a two-step process：
  - 1）A large-domain, coarse spiral score (CSS) function:

$$CSS(\emptyset,\theta) = c_{SS}N^{-1}\sum_{i\in disk}\|\nabla\log(I_i)\times S_i(\emptyset,\theta)\| - c_0$$

  - 2） Calculate the fine spiral score (FSS) using the following formula:

$$FSS = c_{SS}N^{-1}\sum_{i\in disk}\begin{cases}0.62|\nabla\log(I_i)\times \boldsymbol{S}_i(\emptyset,\theta)| - c_0 & where\ |\nabla\log(I_i)\times \boldsymbol{S}_i(\emptyset,\theta)| > 0\\ -|\nabla\log(I_i)\times \boldsymbol{S}_i(\emptyset,\theta)| - c_0 & where|\nabla\log(I_i)\times \boldsymbol{S}_i(\emptyset,\theta)| < 0\end{cases}$$

    - is the number of points in the sample disk;
    - *i* indicates a single point inside the same disk;
    - *I* is the brightness temperature image;

ADT – advanced Dvorak technique

The typhoon positioning method:

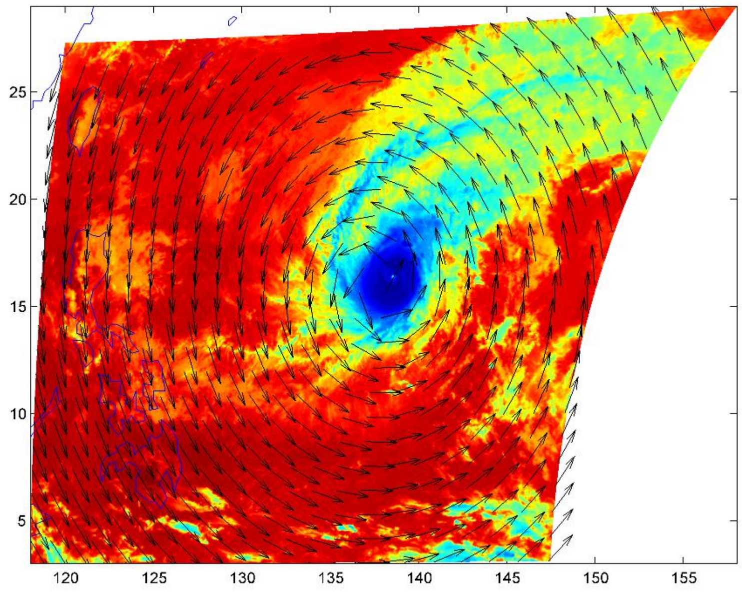


Figure of vector field of spiral and brightness temperature

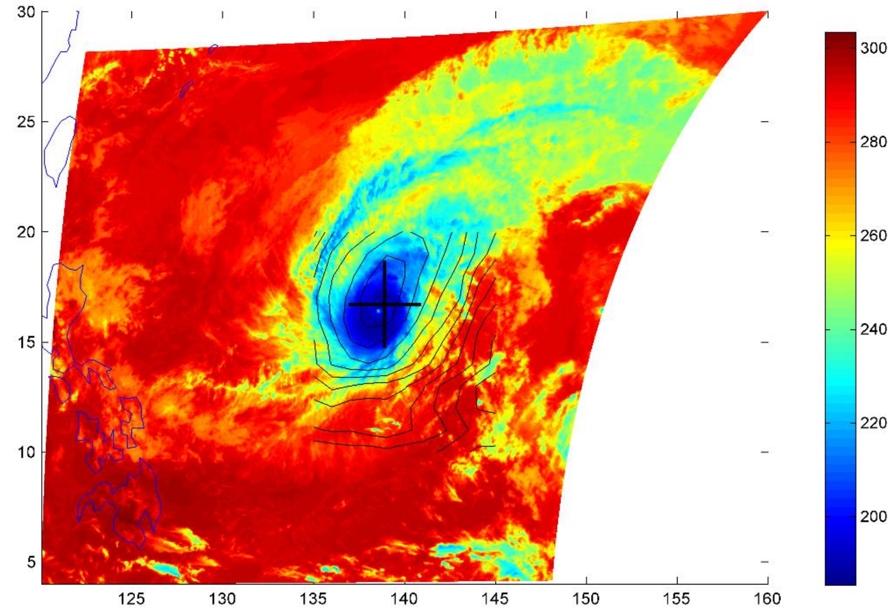


Figure of the scoring field of the spiral and brightness temperature;
"+" is the highest value of the scoring field, which is estimated typhoon center point.

ADT – advanced Dvorak technique

The typhoon positioning method:

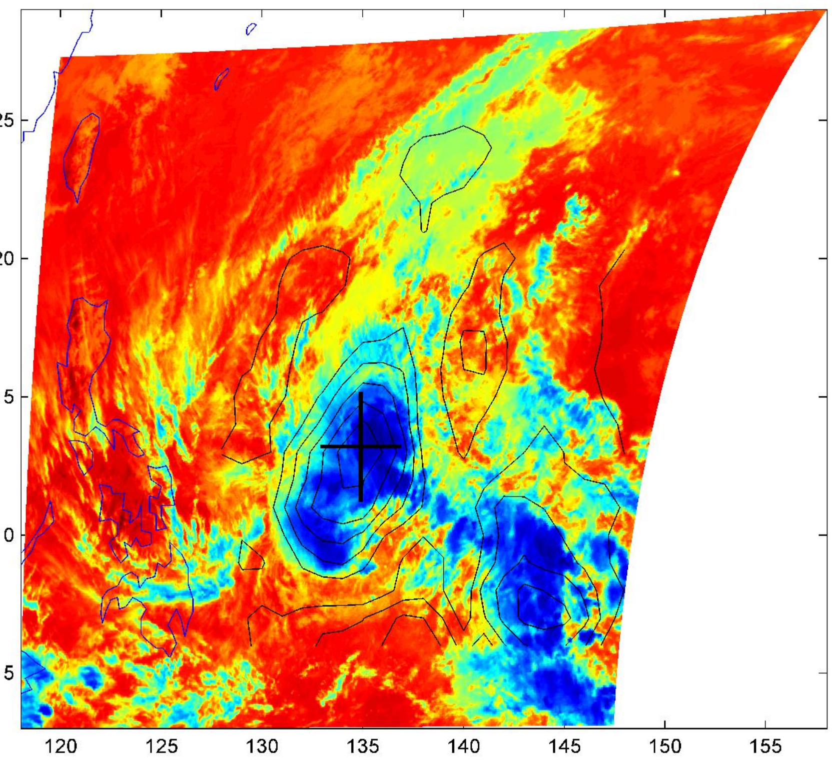
Case Test:

Typhoon Jelawat

International number: 1803

The 3rd named storm of the Pacific typhoon season in 2018.

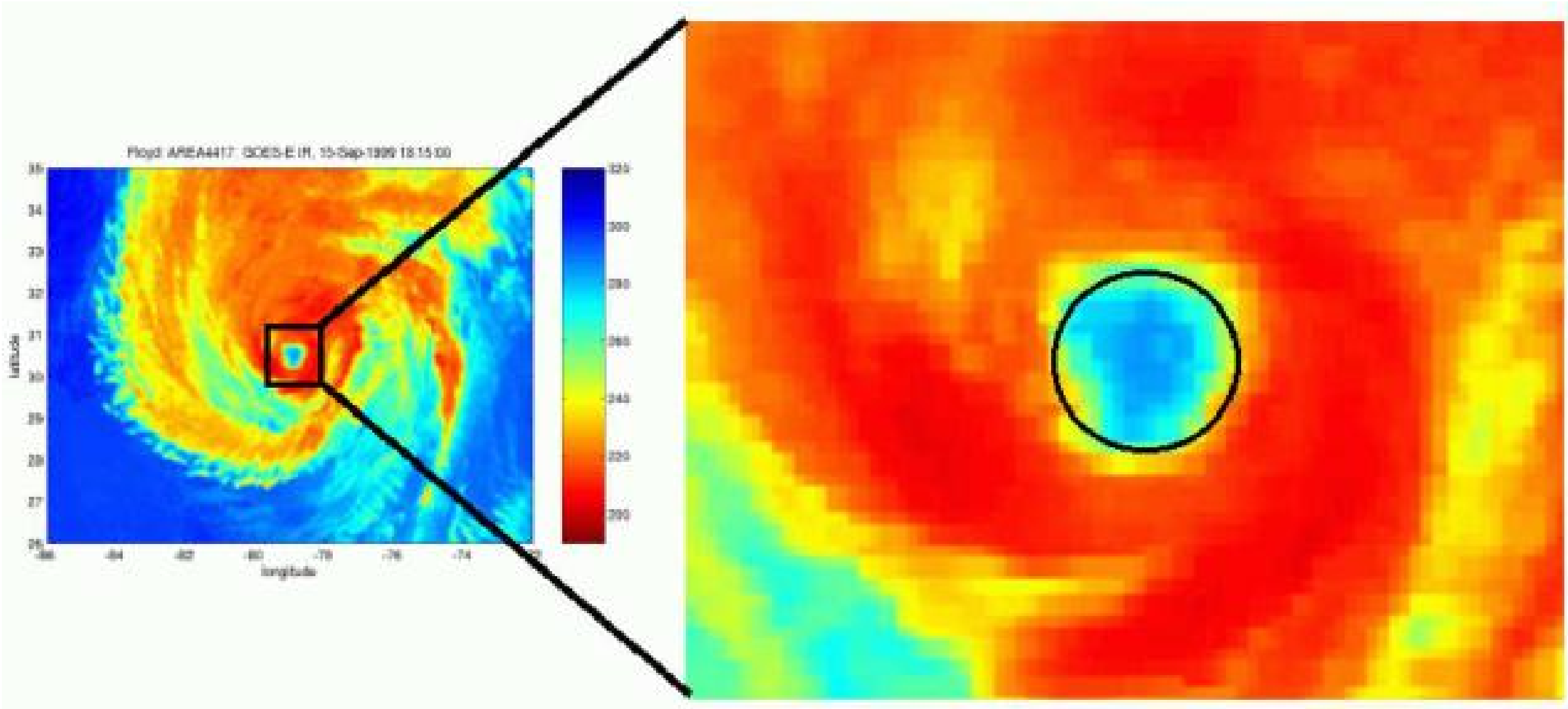
March 27 ~ March 31



ADT – advanced Dvorak technique

The typhoon positioning method:

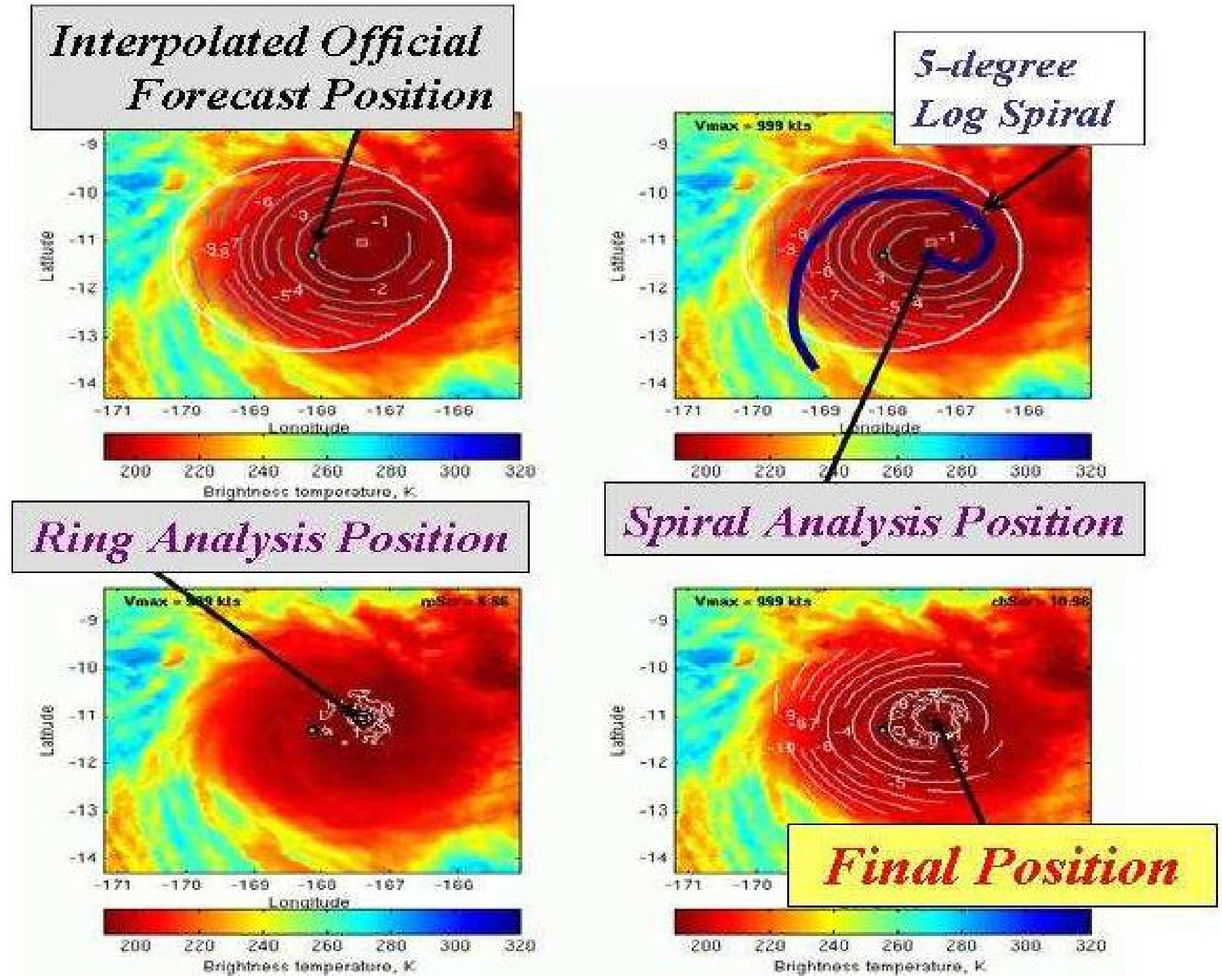
Step 3: Eye ring analysis (black circle) : which best matches temperature gradients of the eyewall feature in the tropical cyclone.



ADT – advanced Dvorak technique

The typhoon positioning method:

Four-panel image showing various steps, and resultant analysis for each step, in the automated storm centering routine.



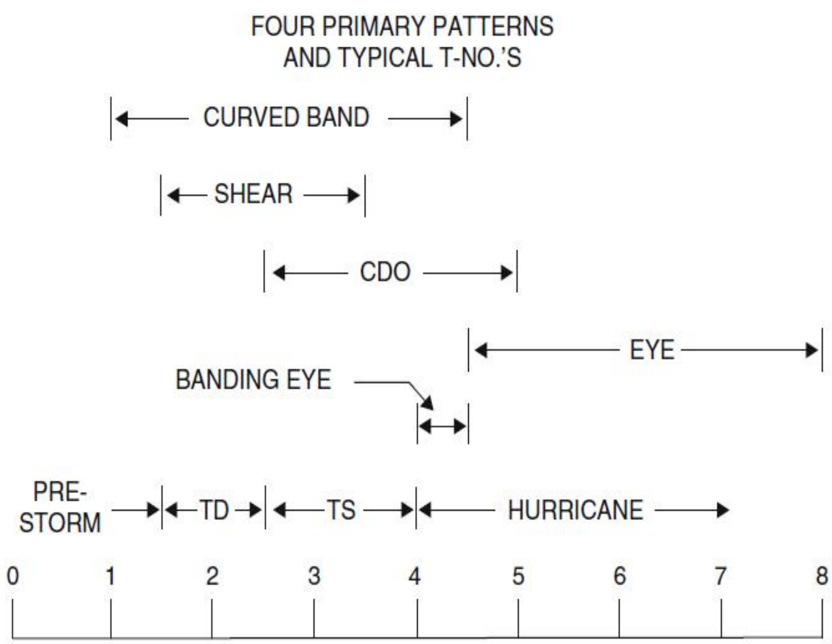
ADT – advanced Dvorak technique

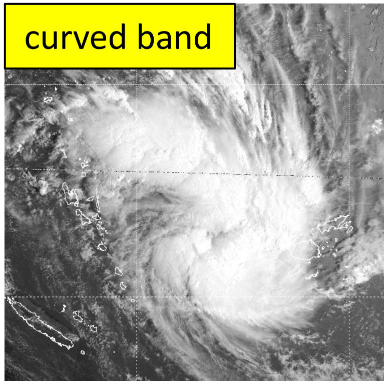
The typhoon intensity estimation:

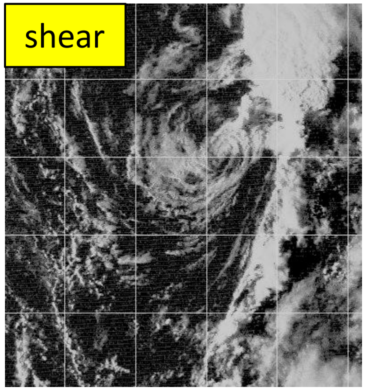
- 1) Scene type determination is fulfilled by a “scene core” determination scheme.
  - The cloud type is divided into four basic categories curved band, shear, central dense overcast (CDO), and eye, with a fifth sub-pattern called a banded eye
- 2) TC Intensity Calculation
  - The algorithm intensity estimates are derived in terms of Tropical Number (T#) and Current Intensity (CI#).
  - Eye and Cloud scene types use regression based algorithm to calculate intensity..
  - Curved band and Shear scene types uses non-regression intensity estimates. .

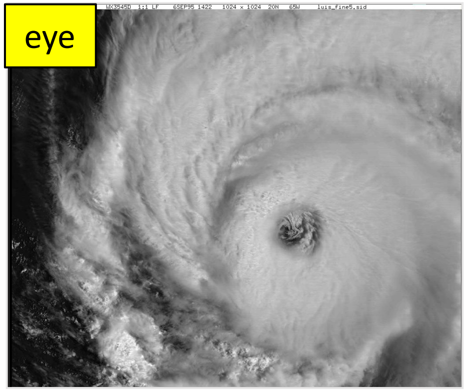
ADT – advanced Dvorak technique

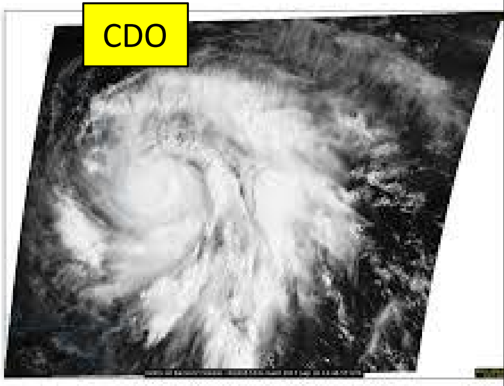
The typhoon intensity estimation:





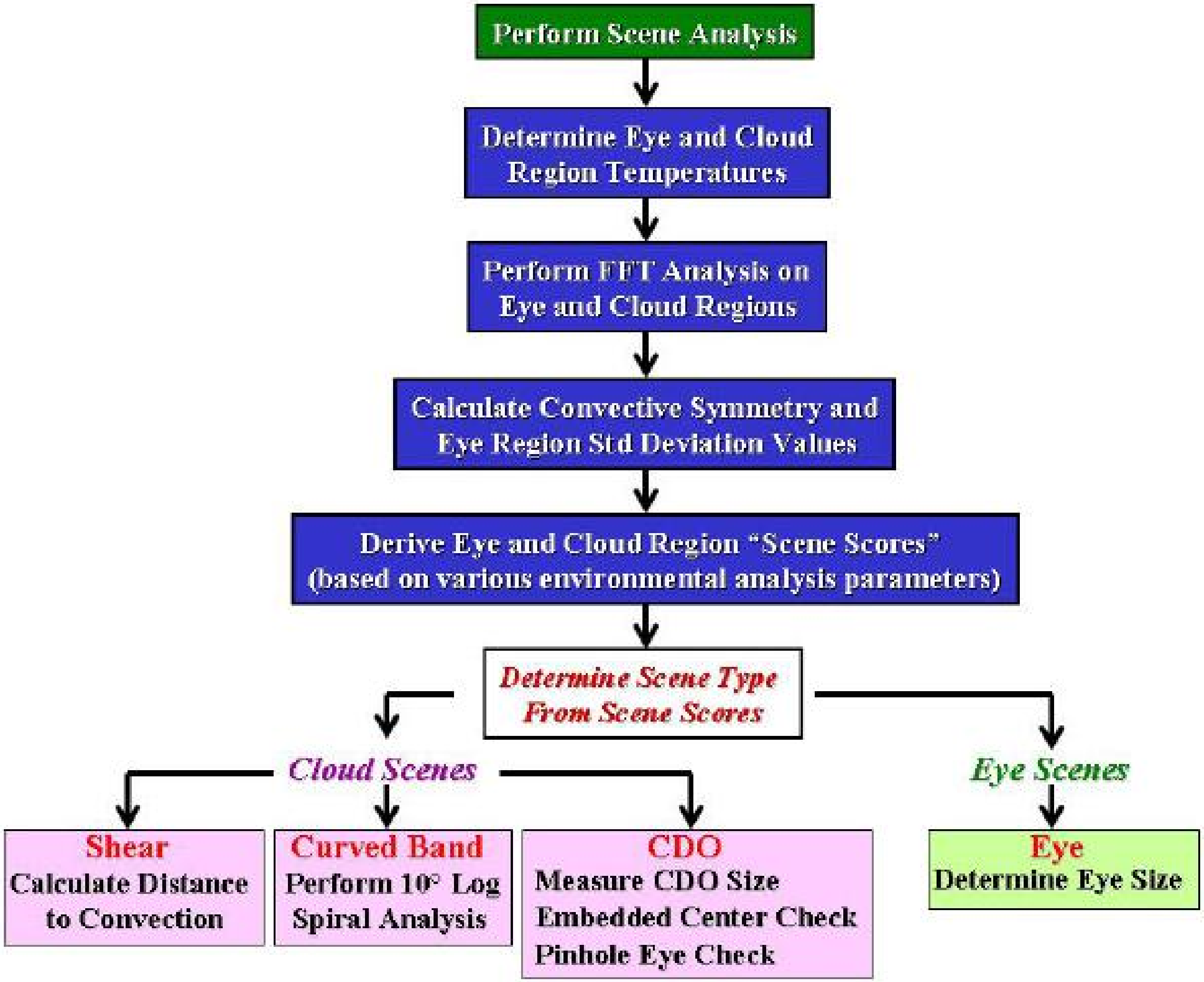






ADT – advanced Dvorak technique

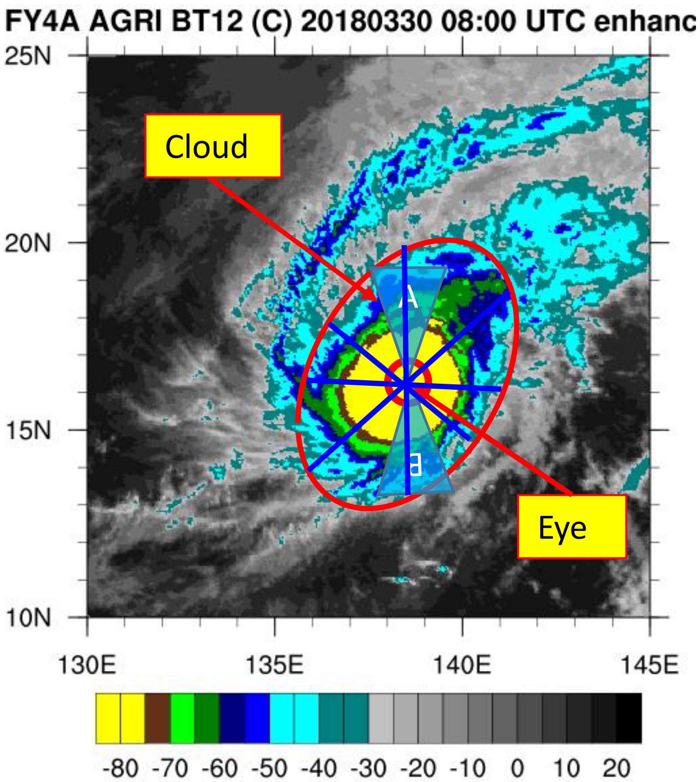
ADT Scene type determination flowchart



ADT – advanced Dvorak technique

The typhoon intensity estimation:

TC intensity estimation of Eye and CDO type



Convective cloud temperature: -54 C ~ - 64 C
Blue and dark blue of the picture

Strong depends on:

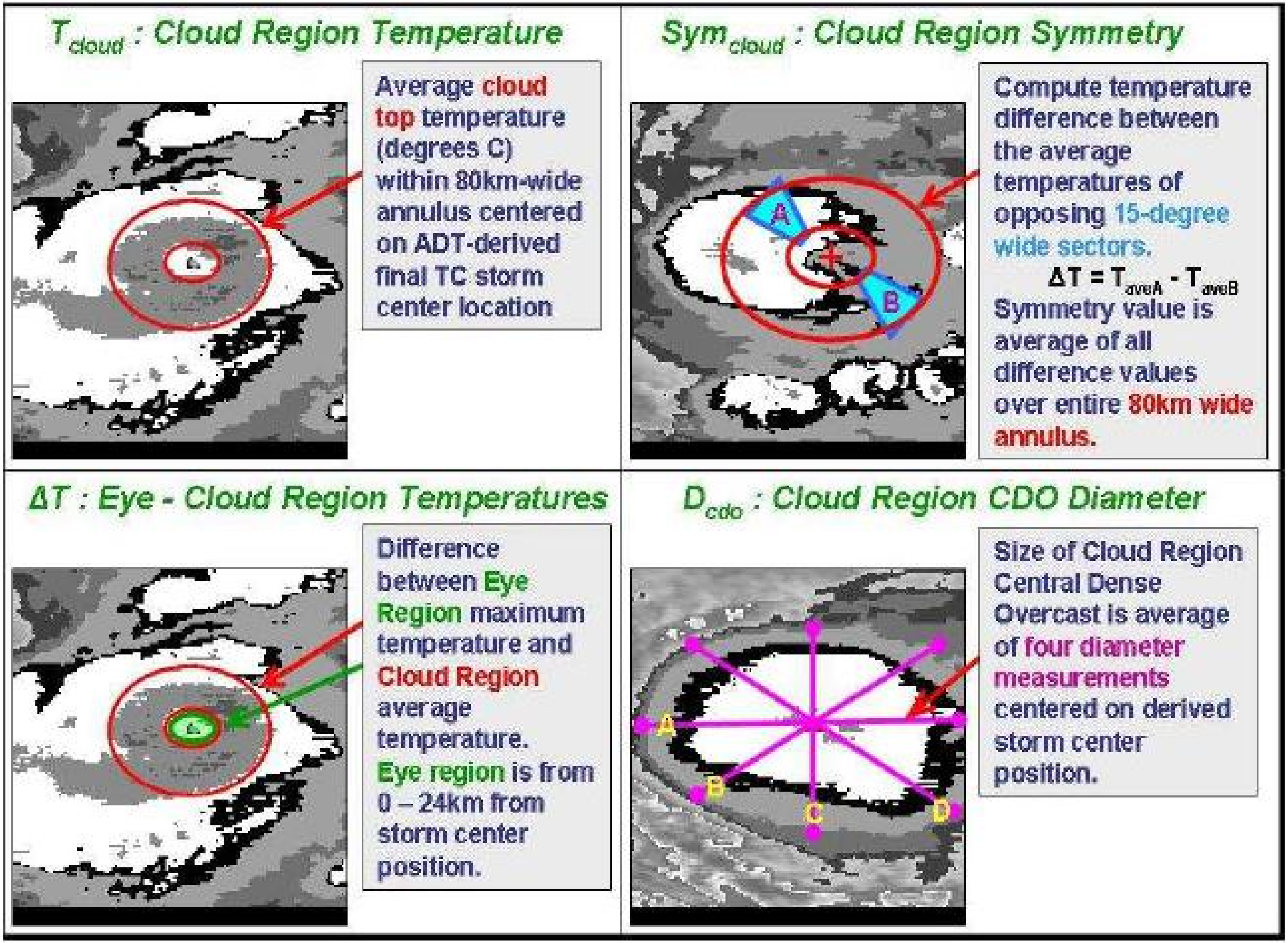
- Difference of eye temperature and temperature of the surrounding cloud (Δ Temp)
- Convection symmetry
- scale of Eye and cloud
- Auxiliary values for other observations, calculations, or inversions

$$T\#_{eye} = 1.10 - 0.07 \times Temp_{cloud} + 0.011 \times \Delta Temp - 0.015 \times Sym_{cloud}$$
$$T\#_{cloud} = 2.6 - 0.02 \times Temp_{cloud} + 0.002 \times D_{cdo} - 0.03 \times Sym_{cloud}$$

Where $T\#_{eye}$ and $T\#_{cloud}$ are calculated intensity for eye and cloud scene, respectively; $Temp_{cloud}$ is the average temperature (˚C) for cloud region; $\Delta Temp$ is temperature difference between eye region maximum temperature and $Temp_{cloud}$; Sym_{cloud} is the symmetry (˚C) of cloud region temperature; D_{cdo} is diameter (km) of cloud region

ADT – advanced Dvorak technique

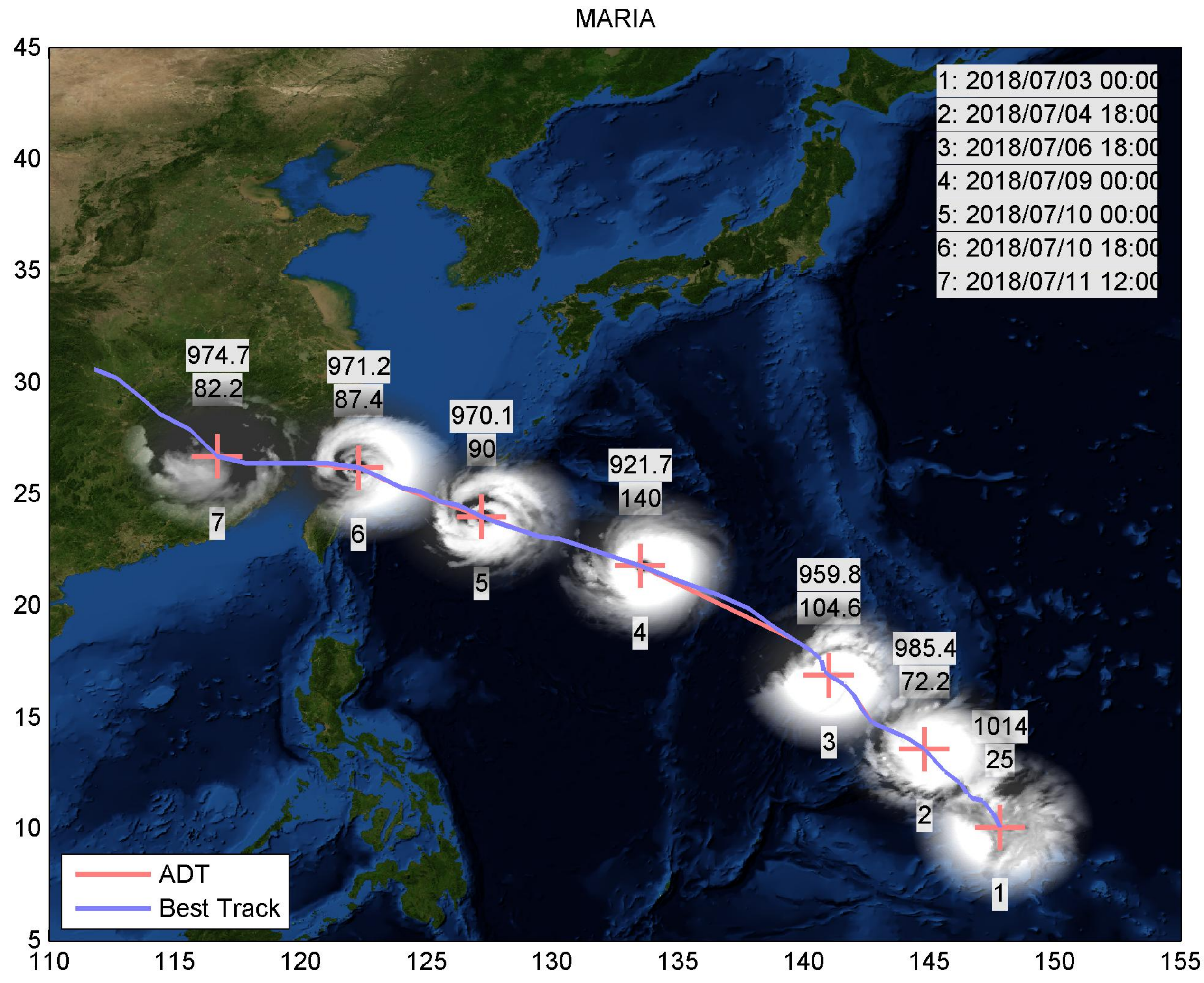
The typhoon intensity estimation:



ADT – advanced Dvorak technique

The typhoon intensity estimation:

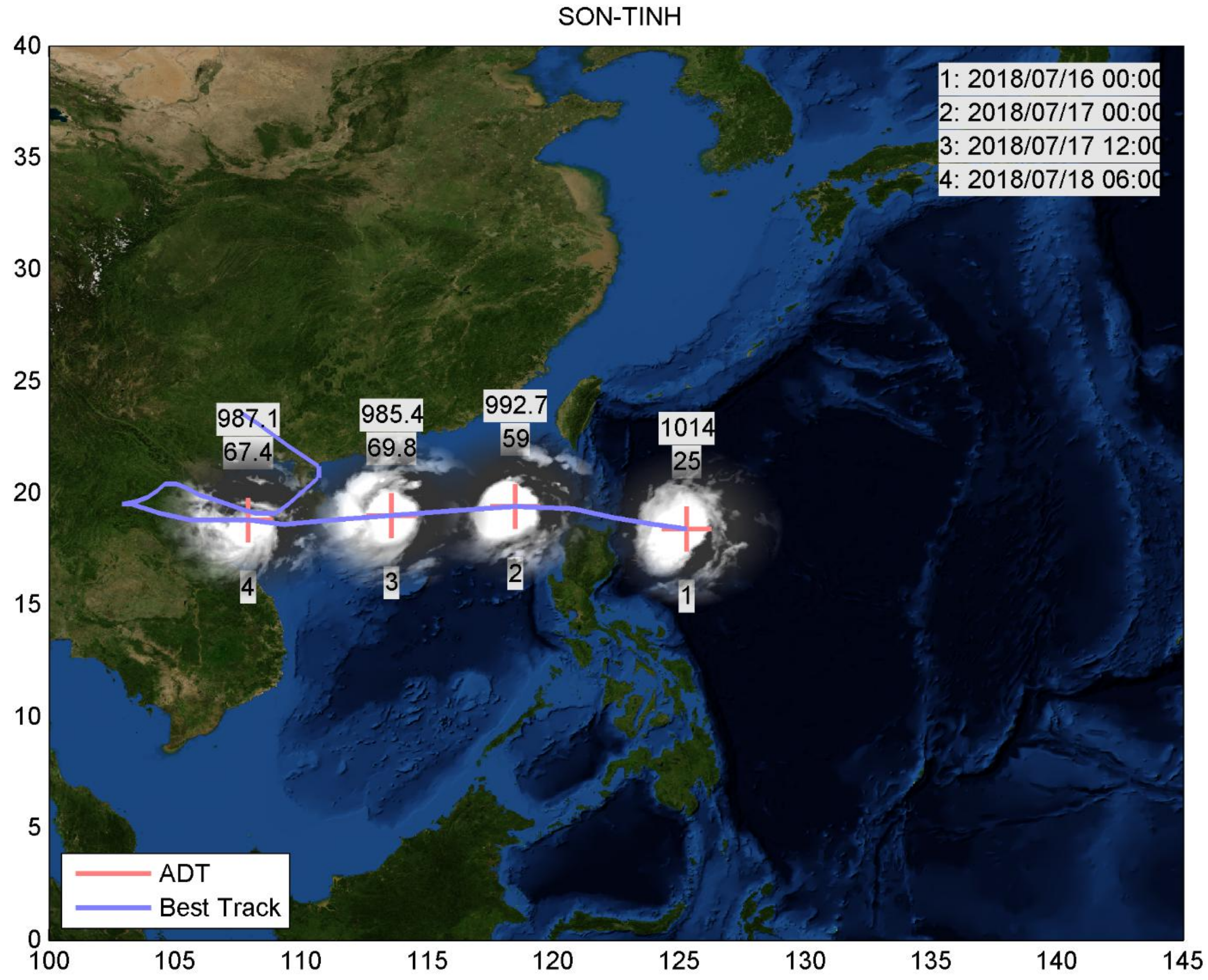
Example of typhoon of ‘eye’ type



ADT – advanced Dvorak technique

The typhoon intensity estimation:

Example of typhoon of CDO type



ADT – advanced Dvorak technique

ADT- Intensity estimation

Intensity estimation of shear

The distance between the first guess and the leading edge of the main convective cloud zone is closely related to the typhoon intensity. The farther the distance, the weaker the typhoon strength.

>=140 km, T#=1.5

140-110 km, T#=2.0

110-80 km, T#=2.25

80-50 km, T#=2.75

50-35 km, T#=3.25

<=35km, T#=3.5 (maximum value）

Intensity estimation of curved band

This method uses a 10° log spiral to measure the amount of convection and determines the amount of curvature.

Step 1: Calculate the number of spiral segments in the -54 to -64 degree.

Step 2: The number of spiral segments from -64 degrees to -70 degrees is calculated.

Step 3: Calculate the number of spiral segments from -70 degrees to -76 degrees.

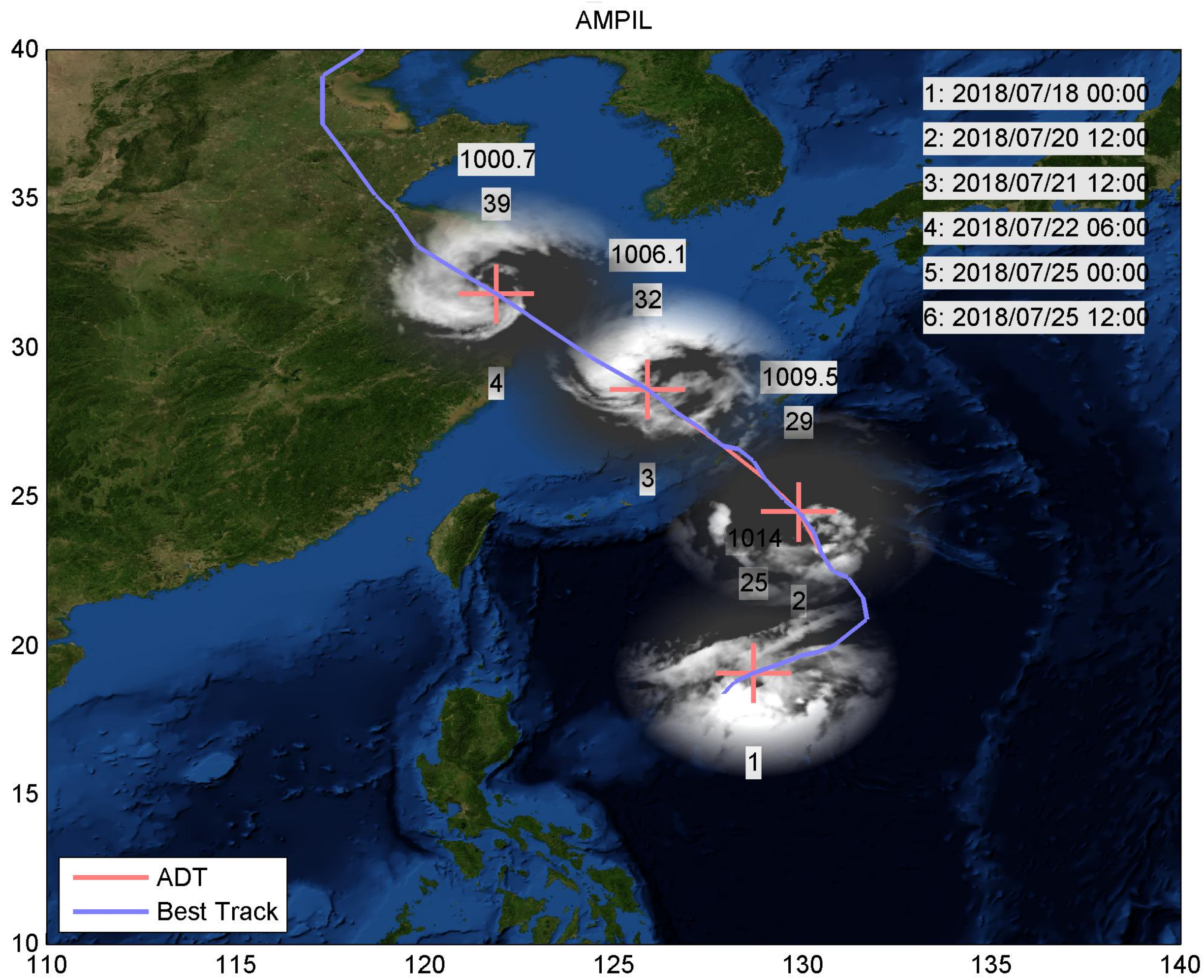
Step 4: Calculate the percentage of segments in the step 2 and 3 to in the -64 to -76 degrees.

Step 5: Calculate the intensity from the percentage.

ADT – advanced Dvorak technique

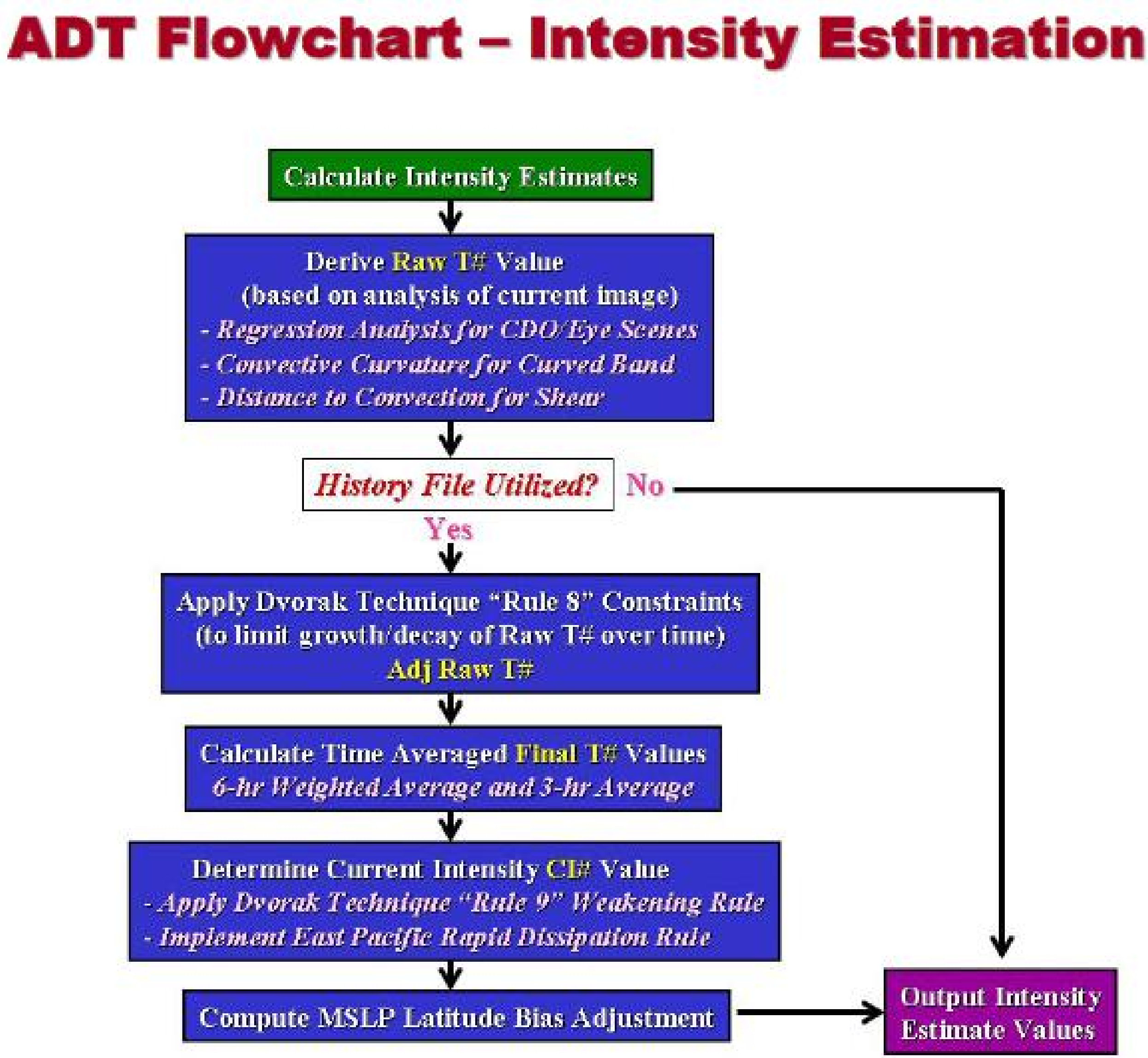
The typhoon intensity estimation:

Example of typhoon of Curved Band type

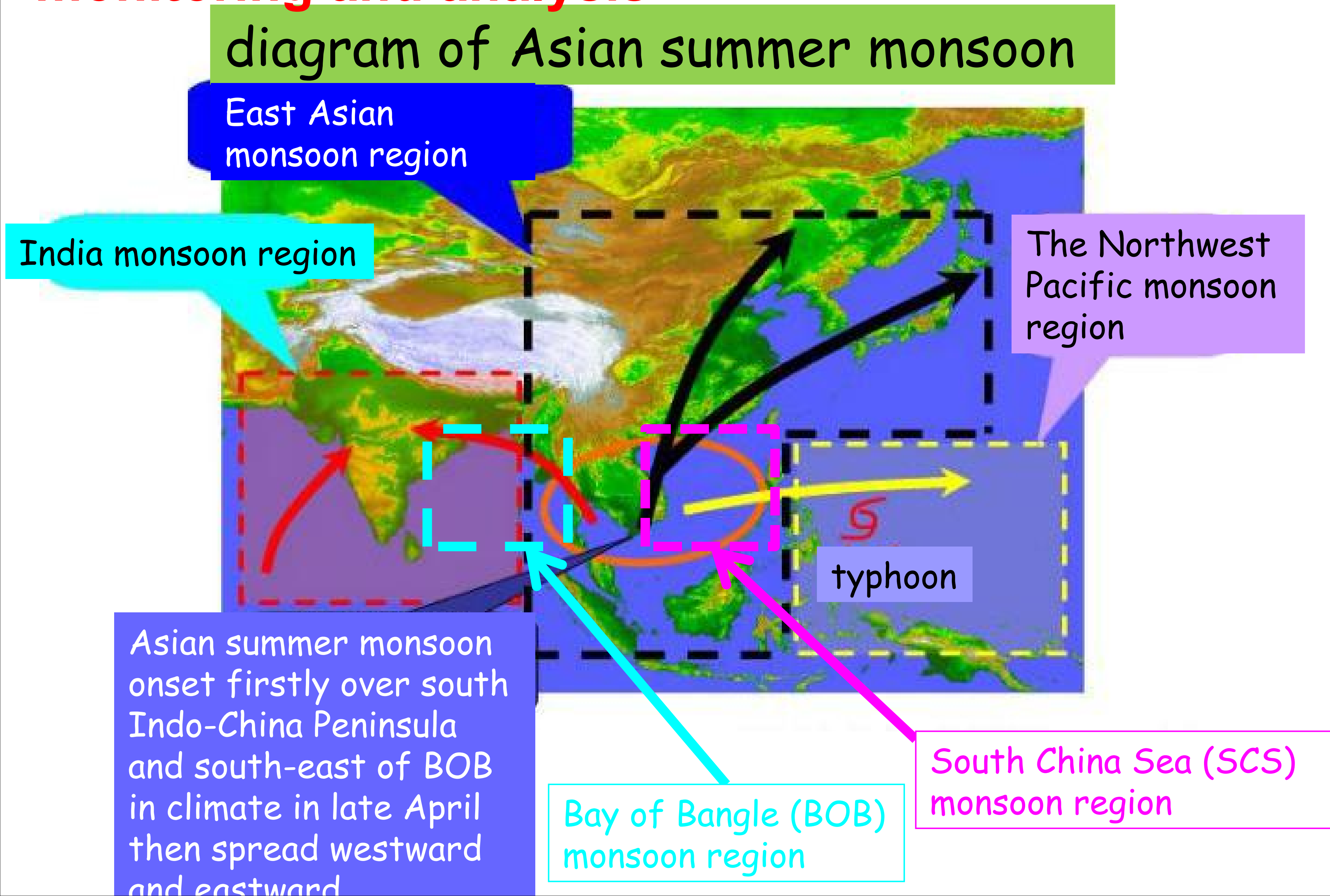


ADT – advanced Dvorak technique

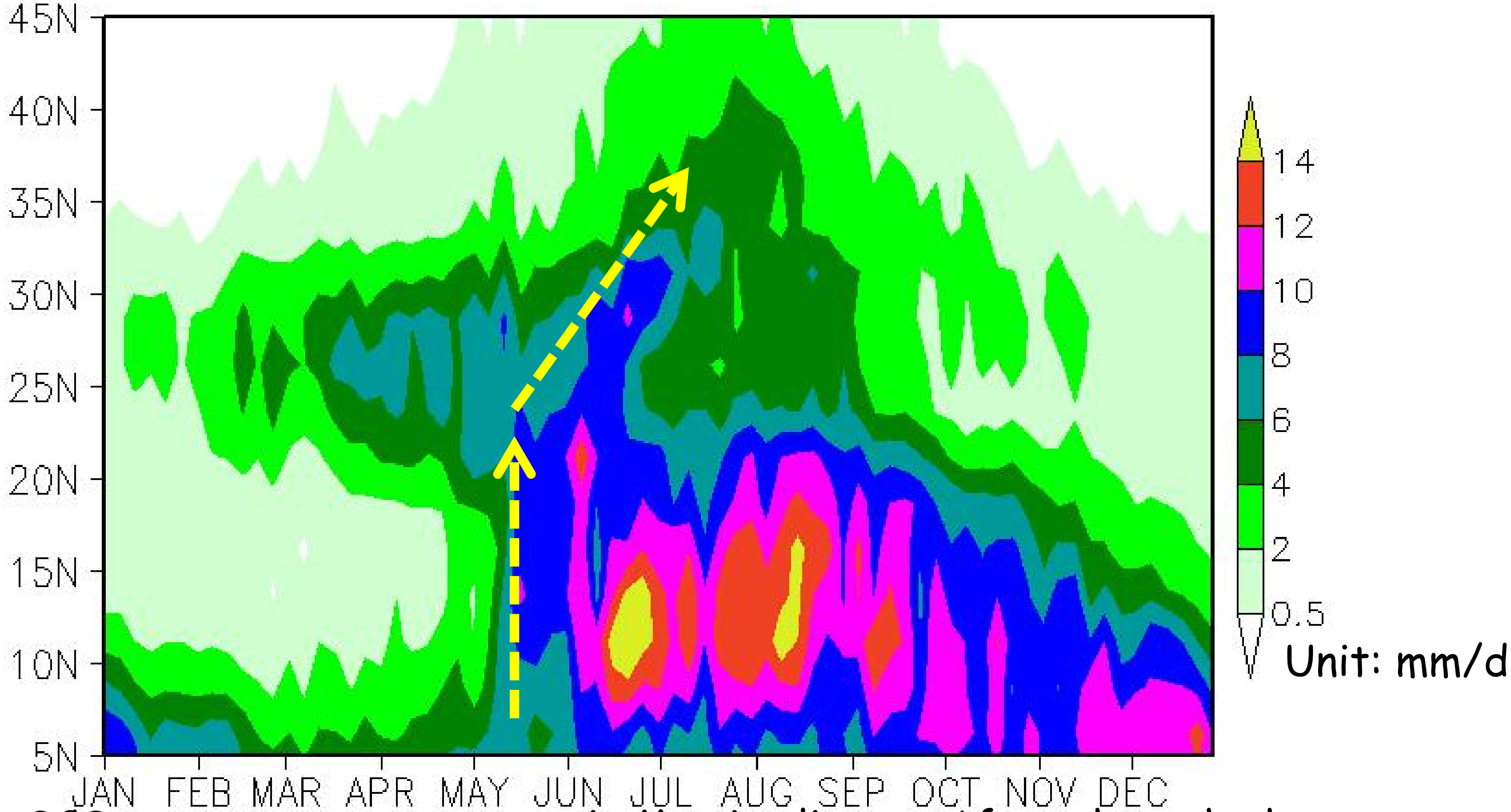
ADT intensity estimation flowchart:



3.FY Satellite data use in Asian summer monsoon monitoring and analysis



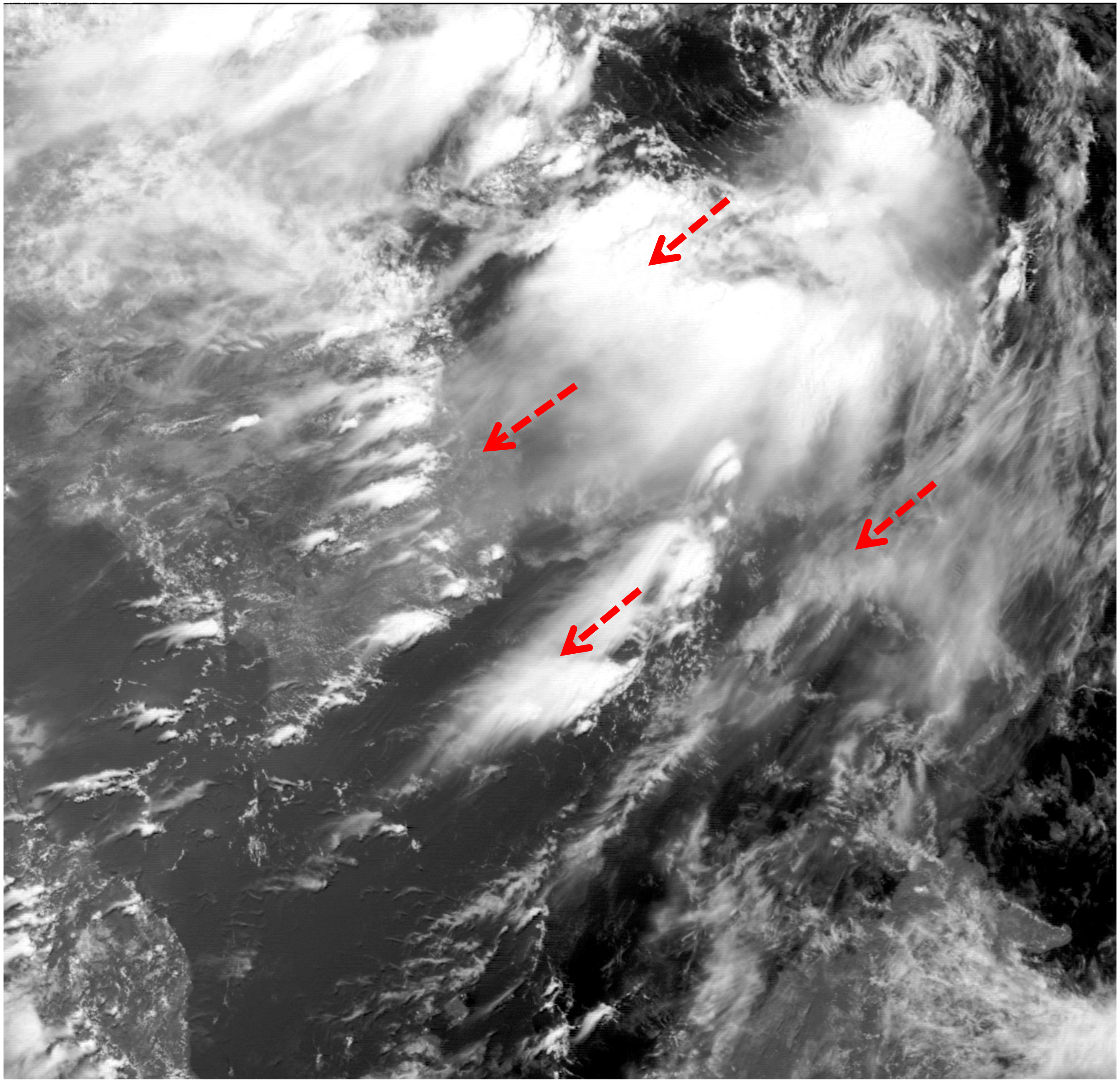
Climate precipitation over the region of (110° -120° E)



The SCS summer monsoon onset in May in climate. After that, the heavy rainfall spreads northward rapidly and has effect on south China. So there are close relationship between SCS summer monsoon and weather in China.

The importance of satellite data in monsoon monitoring

- In tropical and sub-tropical ocean where the Asian summer monsoon happens the conventional meteorological observation data is few. The Asian summer monsoon monitoring is limited.
- The Asian summer monsoon onset is accompanied with convective system and reverse of wind direction which can be detected by meteorological satellite images and some derived products.



After SCS summer monsoon onset the cloud system of a monsoon depression over South China Sea.

The monsoon is mainly due to the thermal difference between land and sea caused by the seasonal variation of solar radiation. Monsoon activity monitoring index is mainly in the following categories:

Circulation index： the index is derived from upper and low troposphere wind.

Temperature and humidity index： the index is derived from OLR(Outgoing longwave radiation)、TBB(temperature of Blackbody brightness)、θ(potential temprature)、temperature or precipitation.

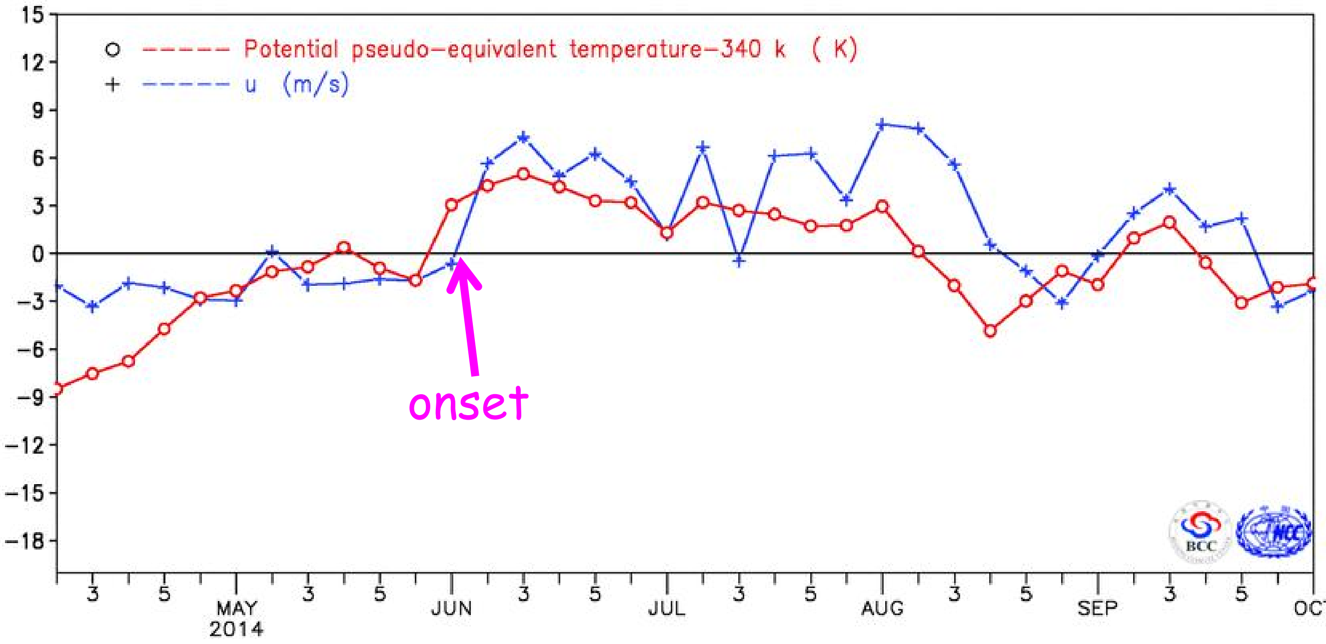
Comprehensive index： using two or more parameters to define the monsoon index.

Operational SCS summer monsoon index in National Climate Center (NCC), China Meteorological Administration (CMA) .

Comprehensive index: low level zonal wind and potential temperature

U850>0 and θ_{se}>340K

（10-20N;110-120E)

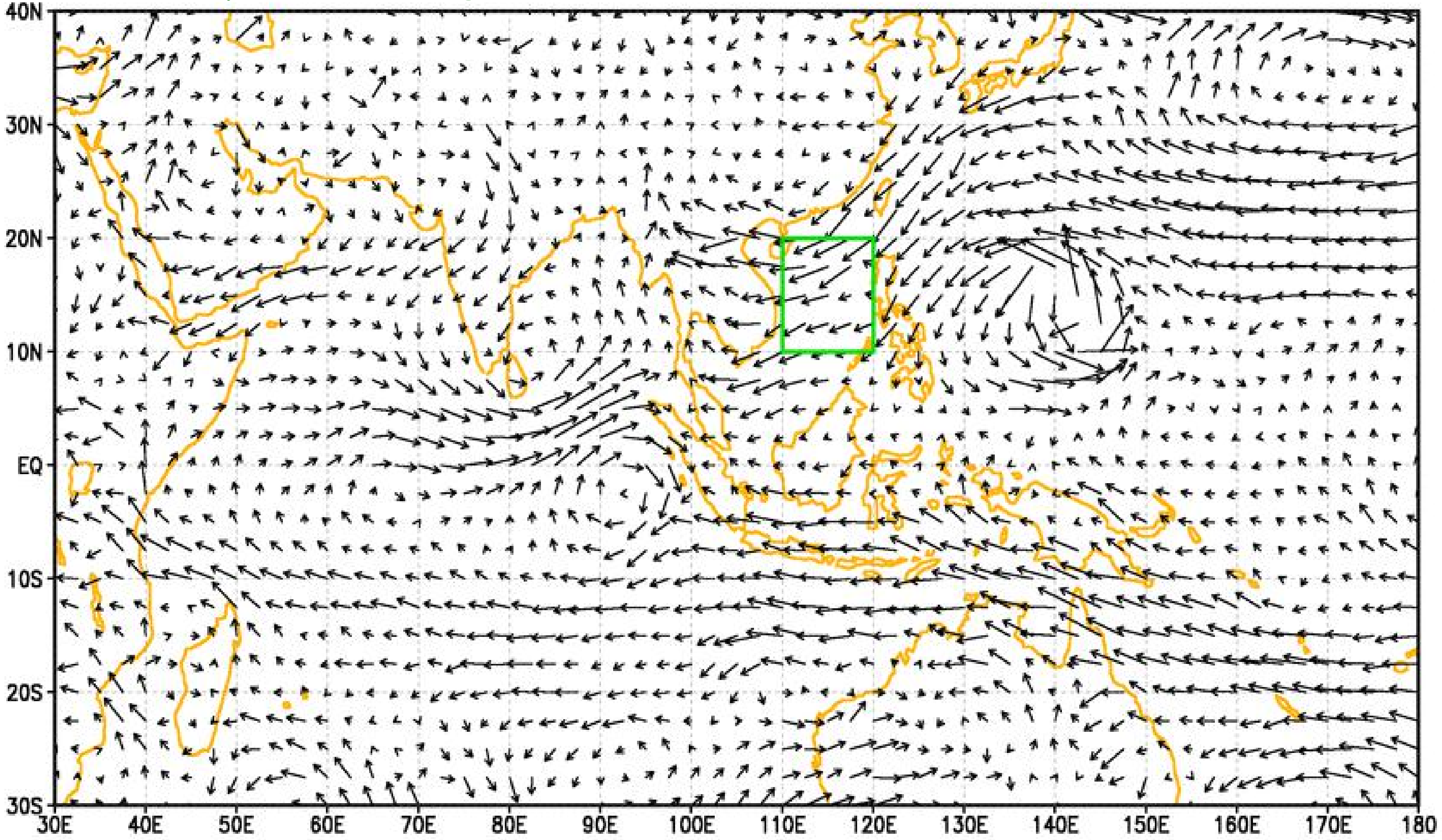


Variation of Zonal wind and Potential pseudo-equivalent temperature over monitoring region

Climate Diagnostics and Prediction Division/NCC/CMA

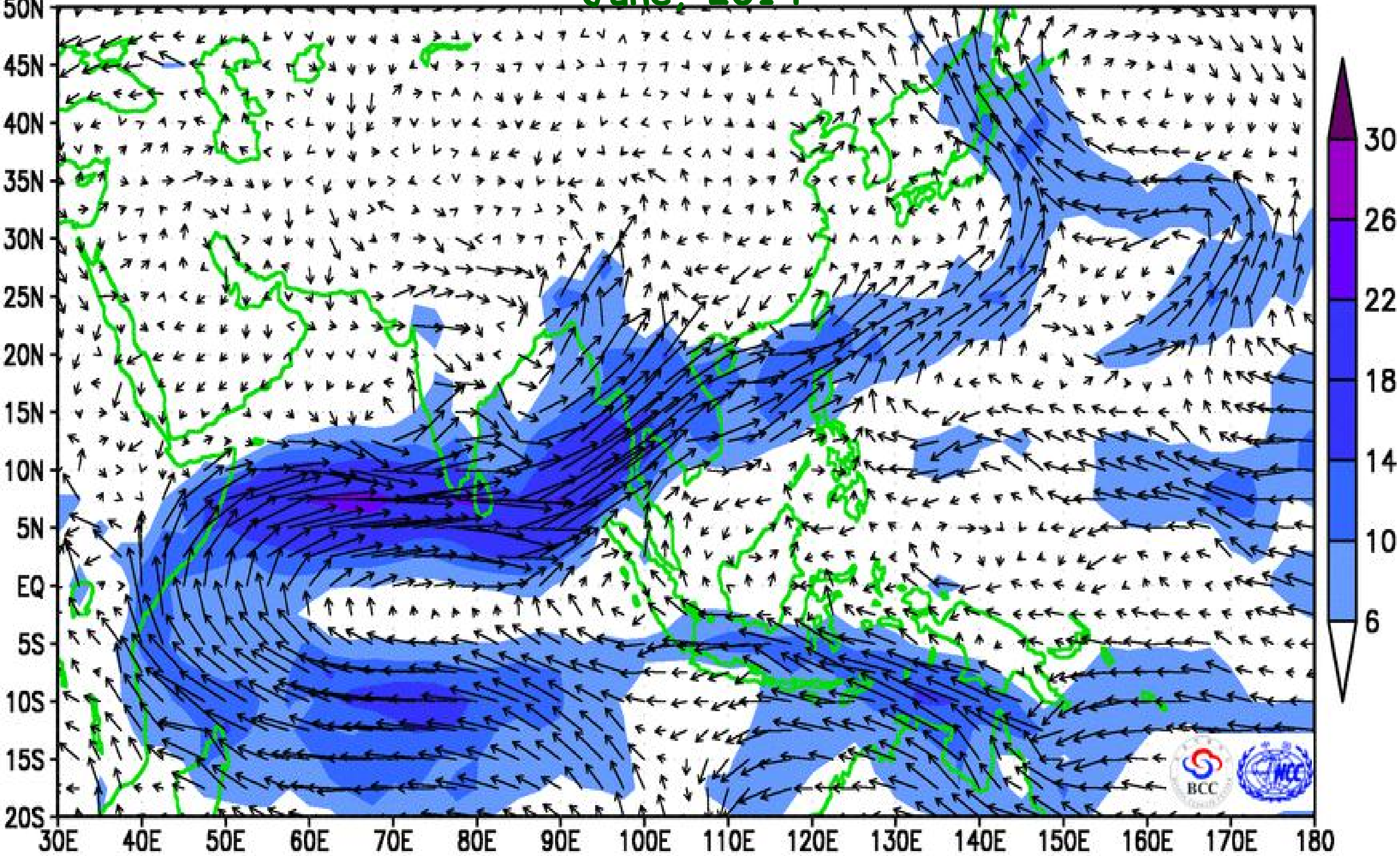
The SCS summer monsoon onset in the 2nd pentad of June,2014.

pentad average wind vector at 850hPa(m/s), Oct, 2013



Before the SCS summer monsoon onset, there are easterlies at the lower troposphere over the SCS.

The 2nd pentad average Water vapor transport at 850hPa(g/s•cm•hPa), June, 2014



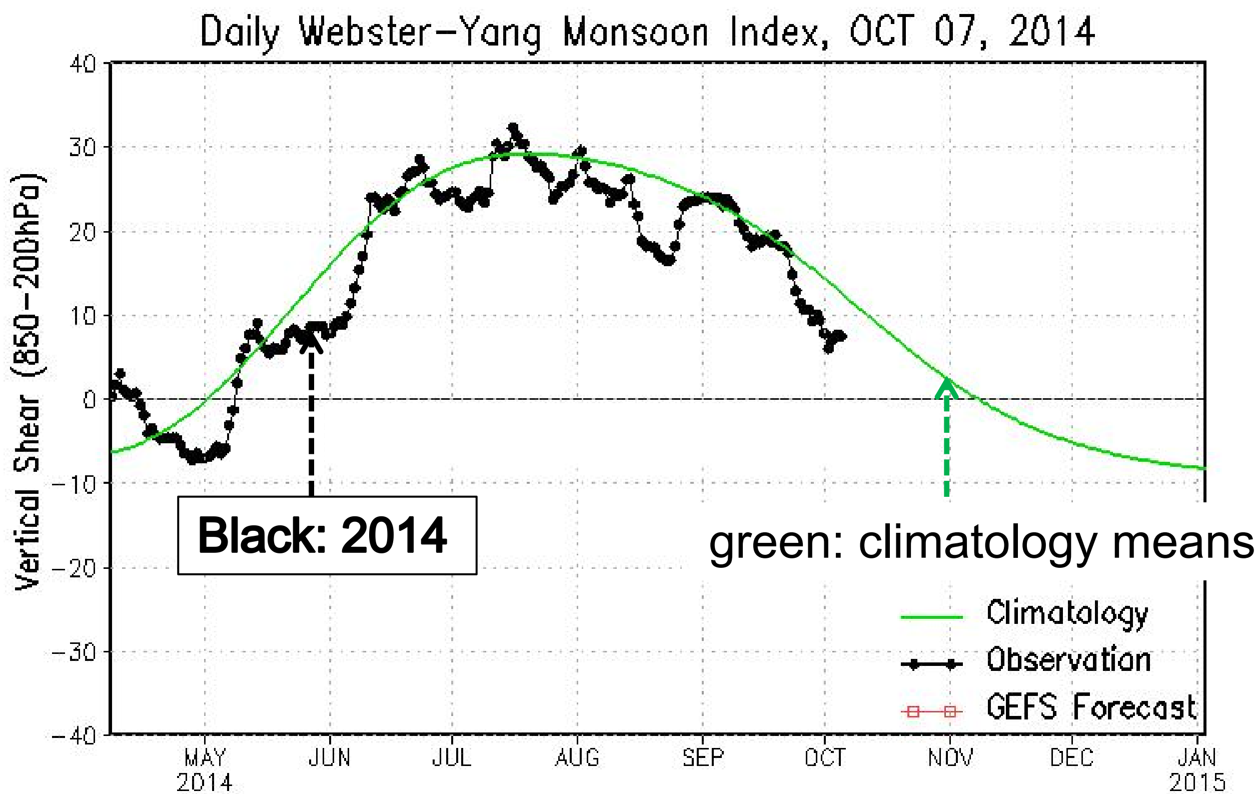
After the SCS summer monsoon onset, there are westerlies and strong water vapor transport at the lower troposphere over the SCS.

Operational Asian summer monsoon index in climate prediction center/National Oceanic and Atmospheric Administration (NOAA), USA.

Webster-yang Asian summer monsoon index: (u850-u200hPa)

u850-u200hPa>0 onset

Vertical wind shear

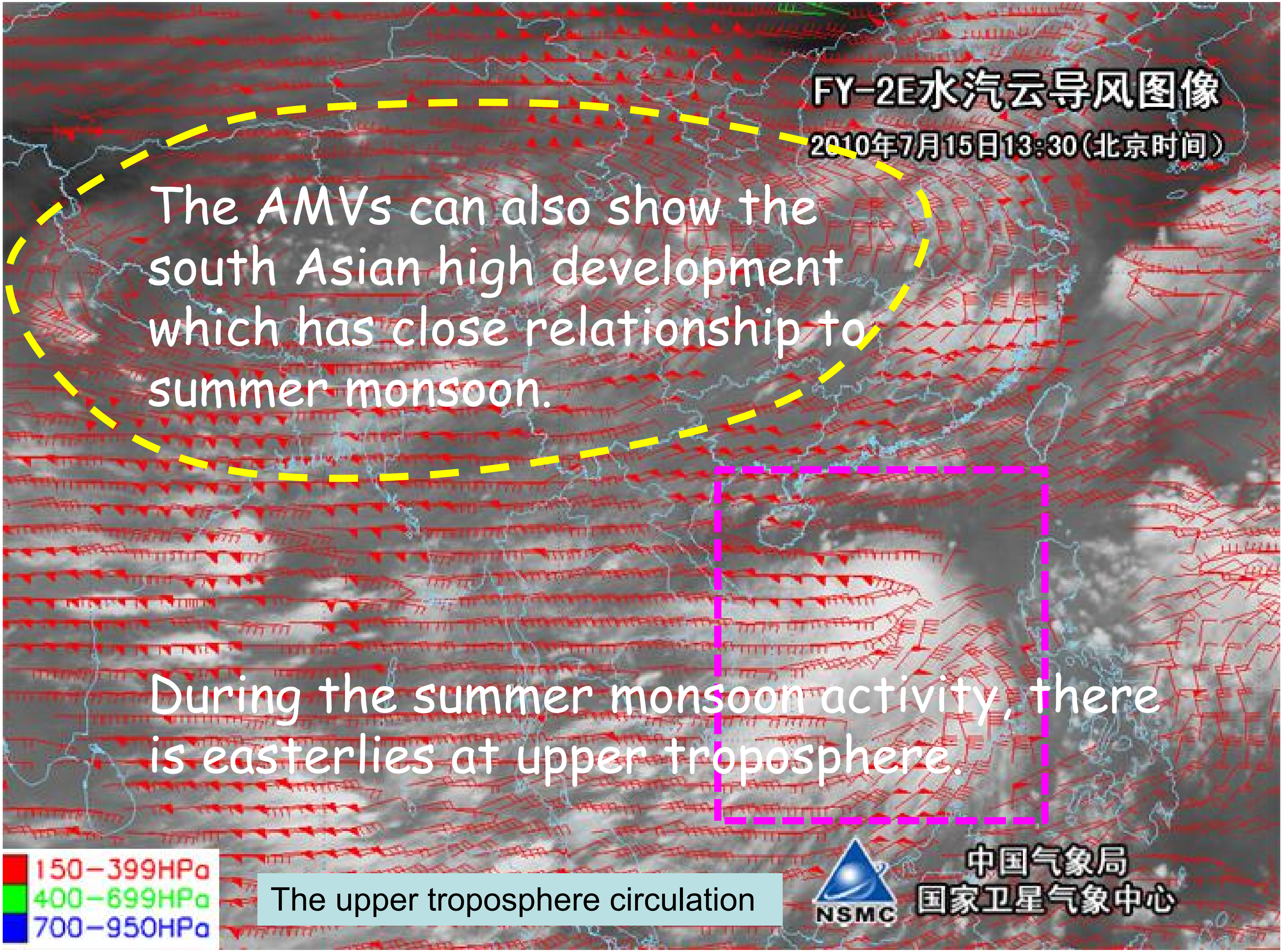


The summer monsoon index is calculated though the re-analysis data

Values above (below) climatologycal means indcate strong (weak) monsoon.

satellite data in SCS summer monsoon monitoring

- AMV (atmosphere movement vector, water vapor channel)
- BB: Temperature of Blackbody Brightness


FY-2E水汽云导风图像
2010年7月15日13:30（北京时间）
The AMVs can also show the south Asian high development which has close relationship to summer monsoon.
During the summer monsoon activity, there is easterlies at upper troposphere.
150–399HPa
400–699HPa
700–950HPa
The upper troposphere circulation
NSMC
中国气象局
国家卫星气象中心

Before summer monsoon onset

After summer monsoon onset

$$\partial T / \partial y < 0$$

$$\partial T / \partial y > 0$$

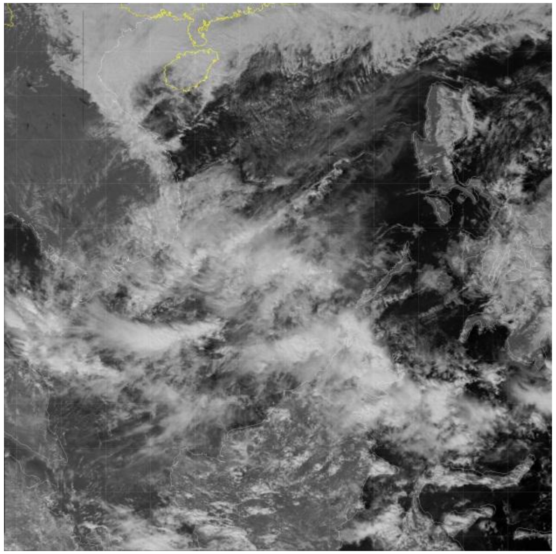
T: average temperature in troposphere

According to the thermal wind relationship

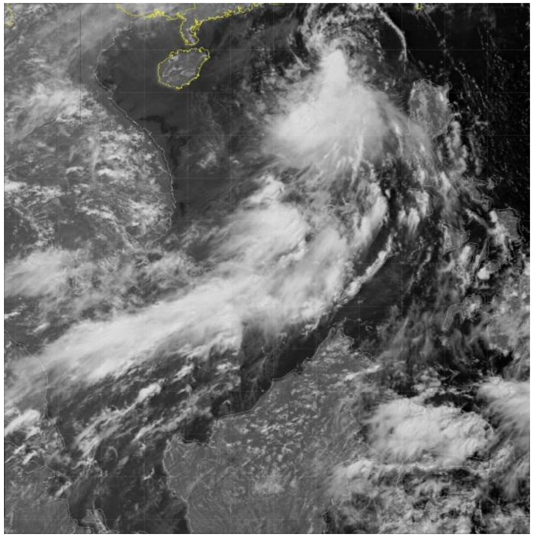
Lower levels: easterlies
upper levels: westerlies

Lower levels: westerlies
upper levels: easterlies

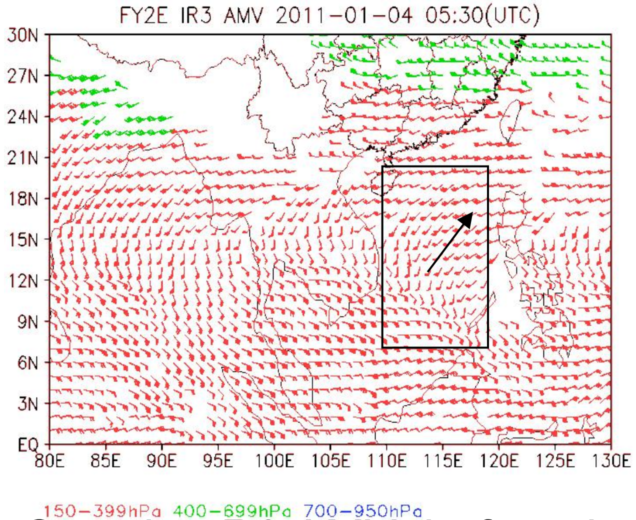
The AMVs in ir3 channel can show the reverse of zonal wind direction at during the summer monsoon onset, so it can be used in summer monsoon monitoring.



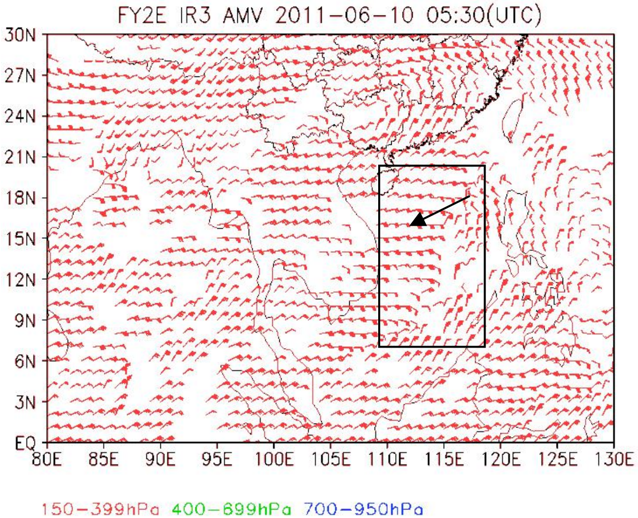
Satellite VIS image before the SCS summer monsoon onset (20110104 0530(utc))



Satellite VIS image after the SCS summer monsoon onset (20110610 0530(utc))



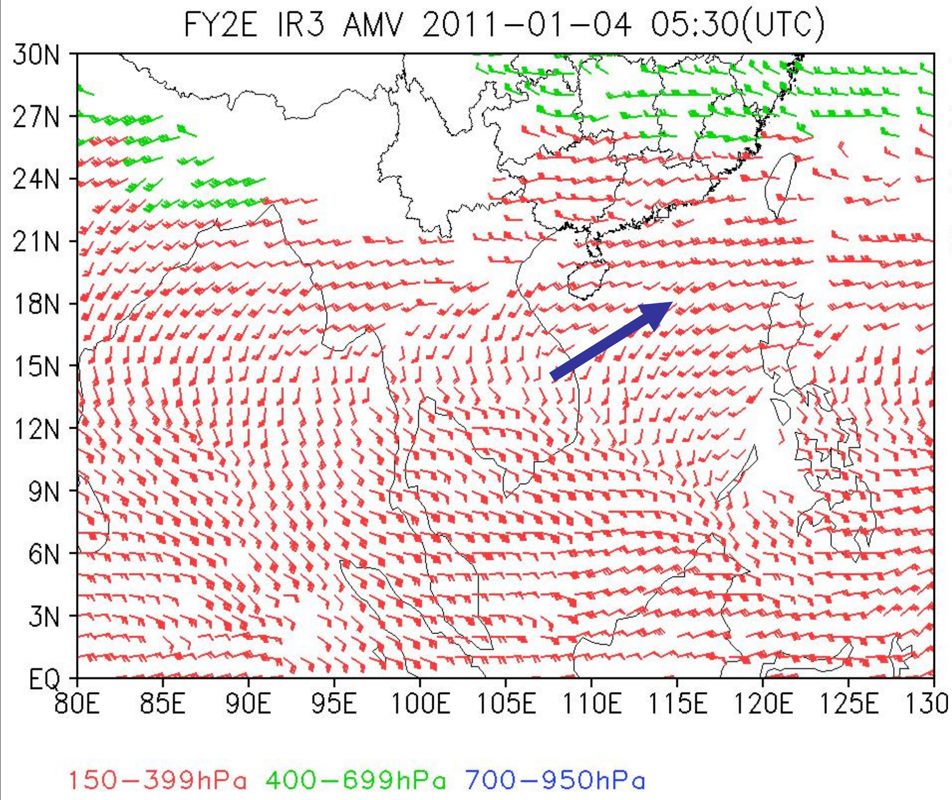
Satellite IR3 AMV before the SCS summer monsoon onset (20110104 0530(utc))

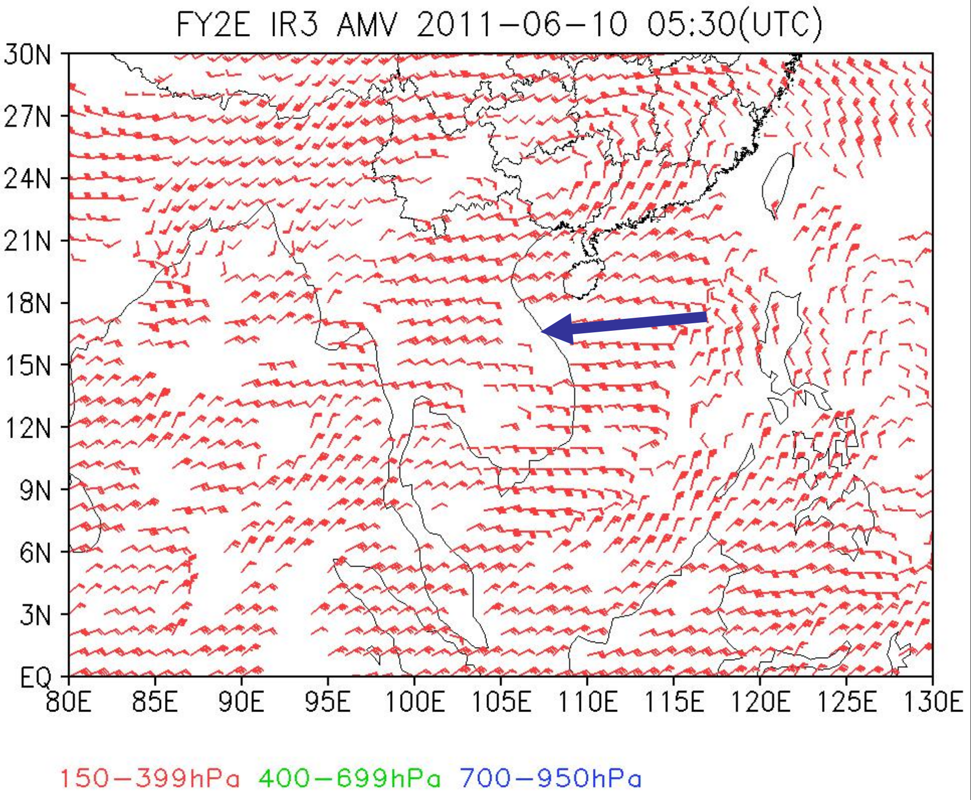


Satellite IR3 AMV after the SCS summer monsoon onset (20110610 0530(utc))

Before summer monsoon onset

After summer monsoon onset





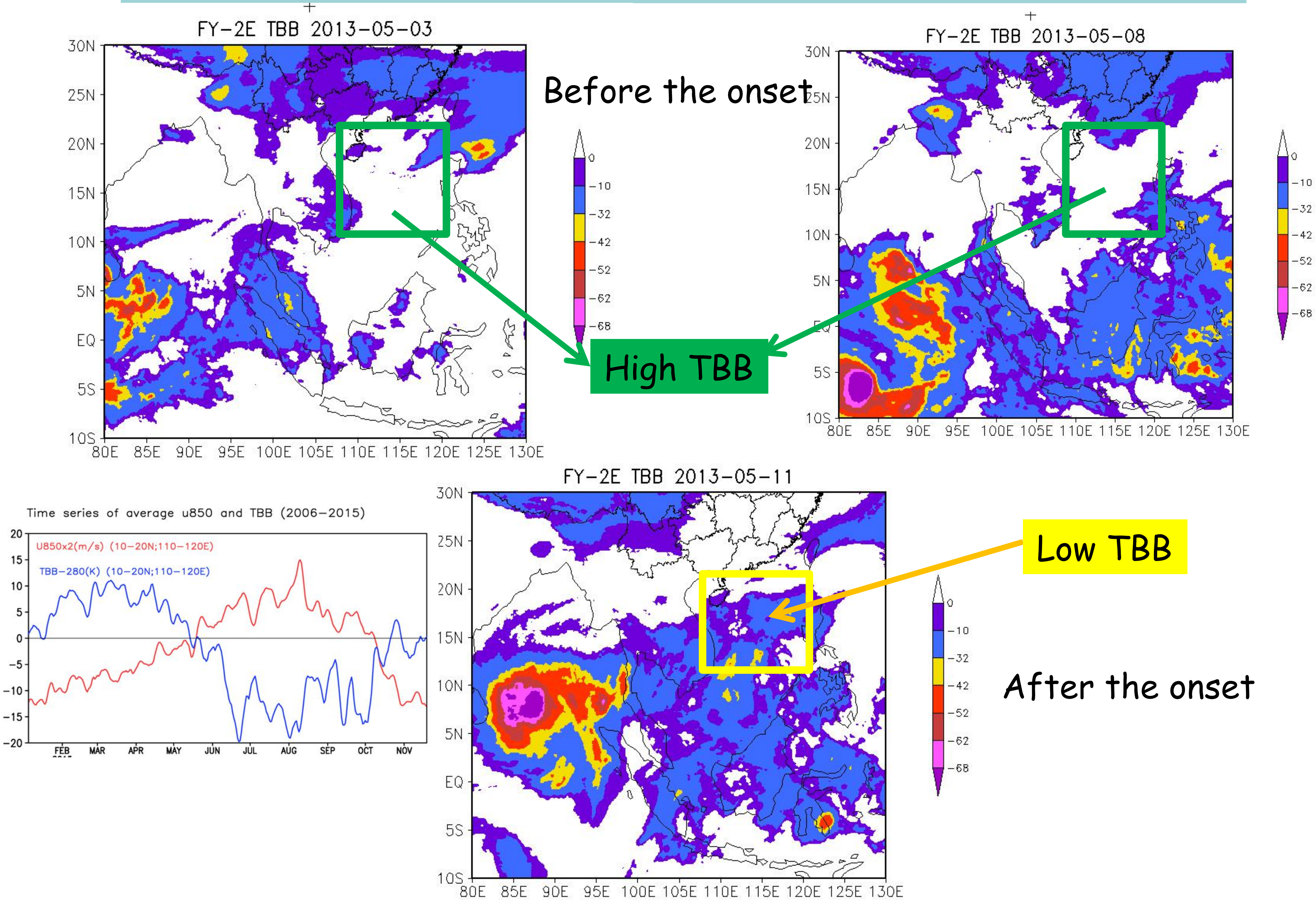
During the SCS summer monsoon onset, the regional average zonal wind changes from west to east. This characteristic can be used in SCS summer monsoon monitoring.

TBB can be used in convection monitoring during the SCS summer monsoon onset.

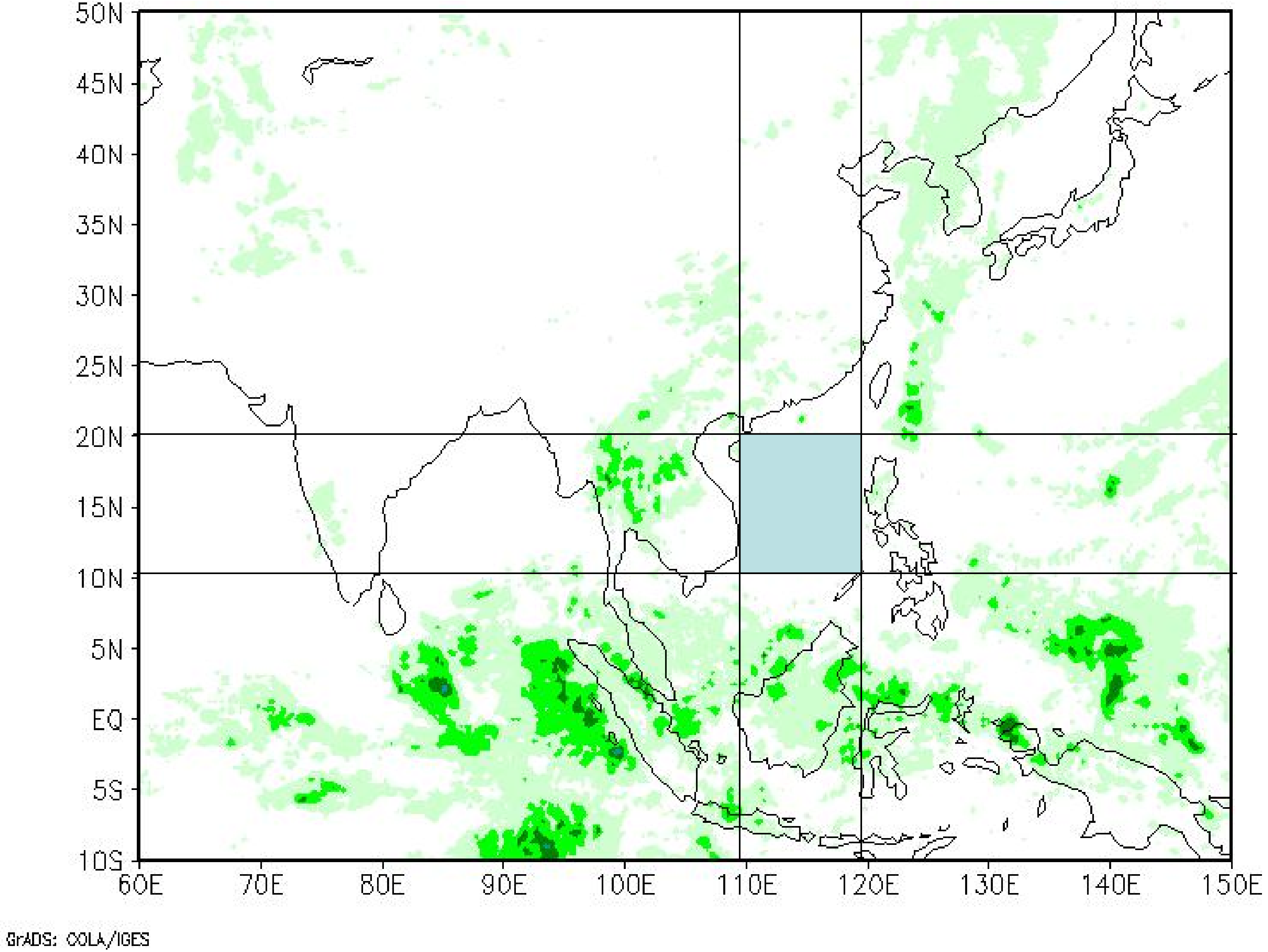
Summer monsoon onset index

TBB <273K

During the SCS summer monsoon onset the daily average TBB in 2013



The SCS summer monsoon area using satellite data monitoring



The method of the SCS summer monsoon monitoring using satellite derived data **AMV and TBB.**

AMV:

$$SCSsm\_index = -\left(\sum_{lon=110^\circ}^{lon=120^\circ} \sum_{lat=5^\circ}^{lat=20^\circ} \sum_{lev=399hPa}^{lev=150hPa} AMV\_u\right) / m$$

SCS monsoon index

m — the grid number in the region of (10 ° -20 ° N， 110 ° -120 ° E) form 150 to 399hPa of the AMV data.

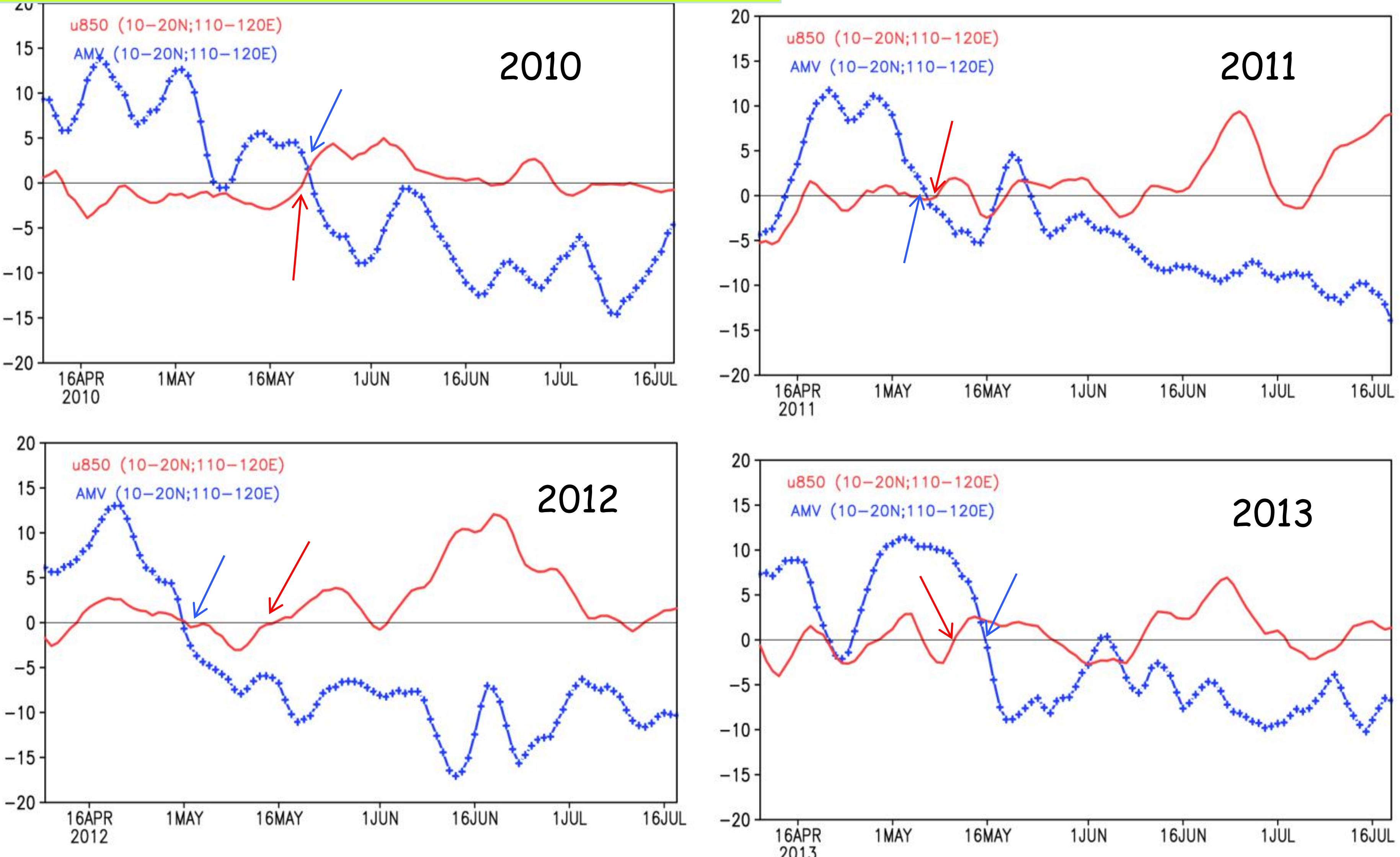
TBB:

$$SCScon\_index = \left(\sum_{lon=110^\circ}^{lon=120^\circ} \sum_{lat=5^\circ}^{lat=20^\circ} TBB\right) / \mathrm{k}$$

SCS monsoon convection index

k — the grid number in the region of (10 ° -20 ° N， 110 ° -120 ° E) of the TBB data.

The compare of summer monsoon index use AMV and low level wind（u-850).

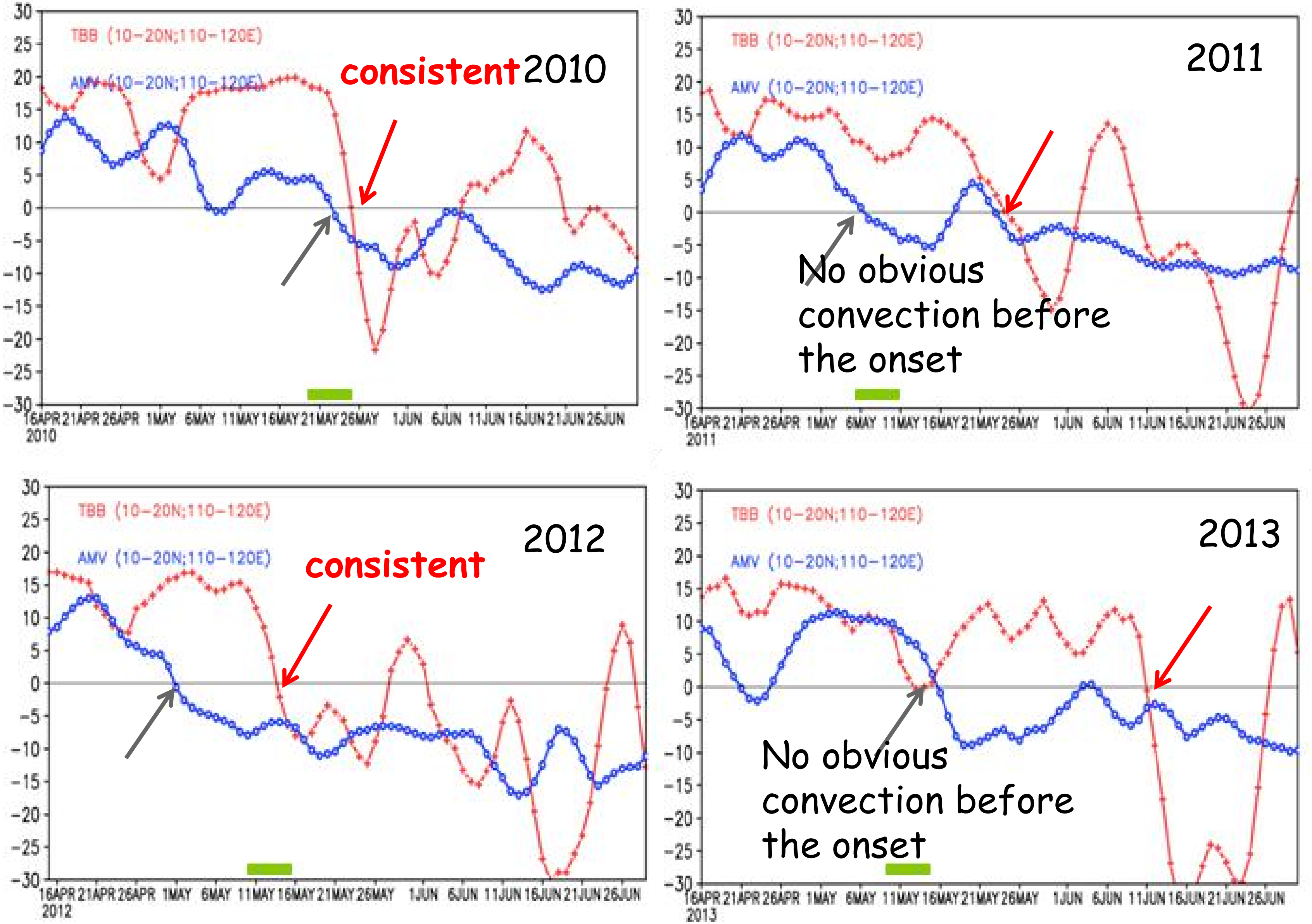


Red curve:u850 blue curve:AMV

The comparison of summer monsoon index using AMV and 850hPa wind

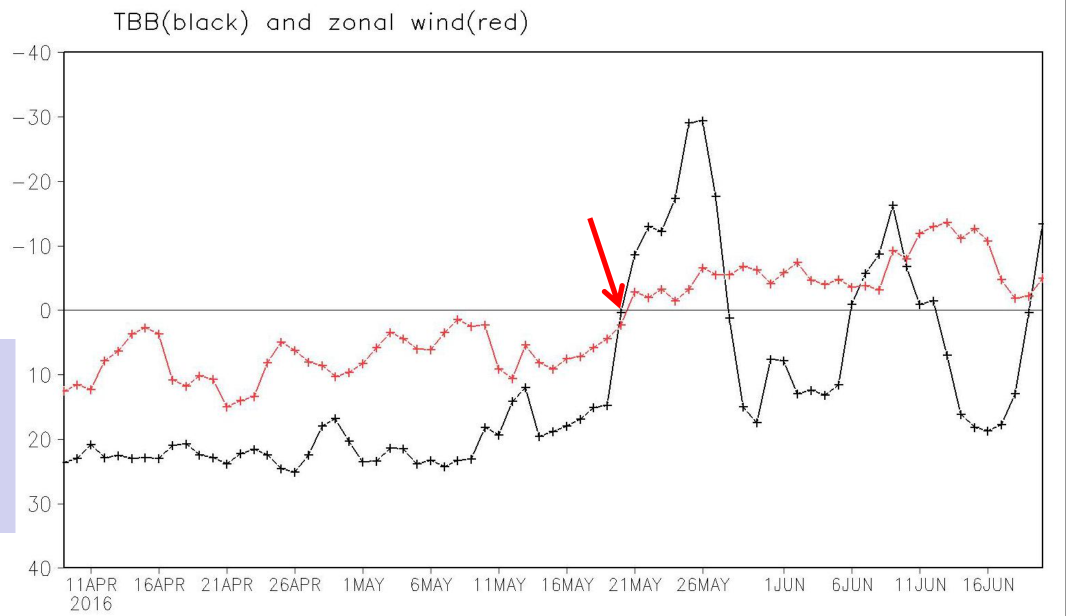
	2006	2007	2008	2009	2010	2011	2012	2013	2014
AMV	5.6	5.23	5.3	5.26	5.22	5.7	5.1	5.16	5.12
u850	5.17	5.19	5.3	5.26	5.21	5.9	5.14	5.11	6.5
difference	11	4	0	0	1	2	13	5	23

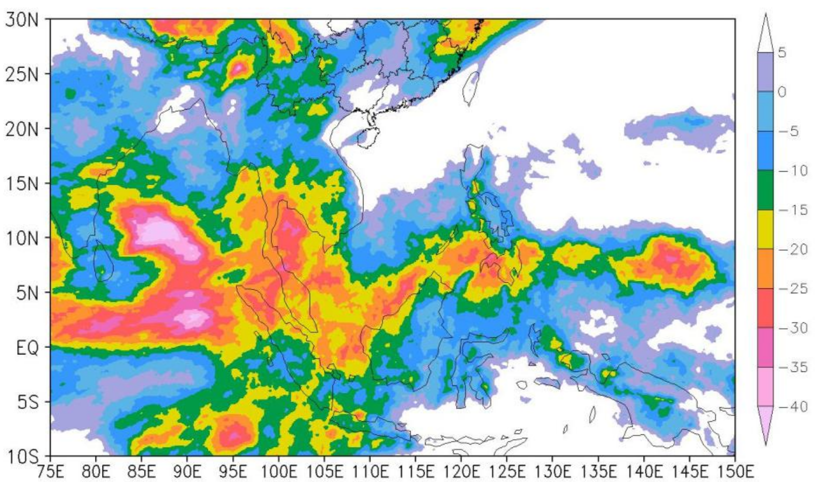
Shall the TBB be used as another SCS monsoon onset index?



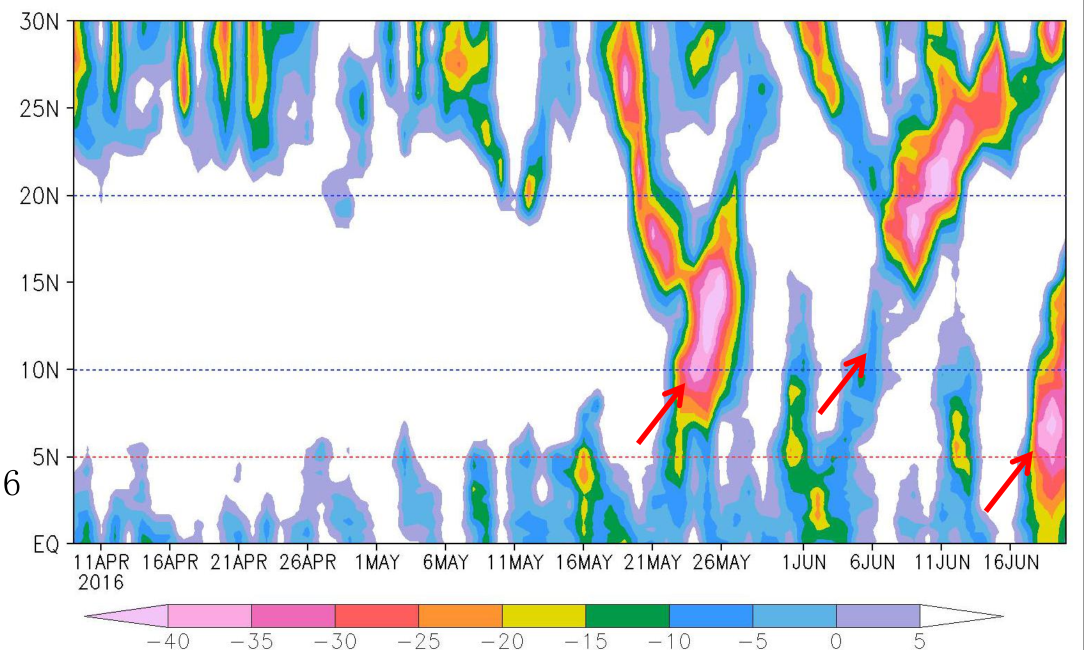
The SCS Summer Monsoon monitoring in 2016

In 2016, the SCS summer monsoon onset date is the 5th pentad, May.



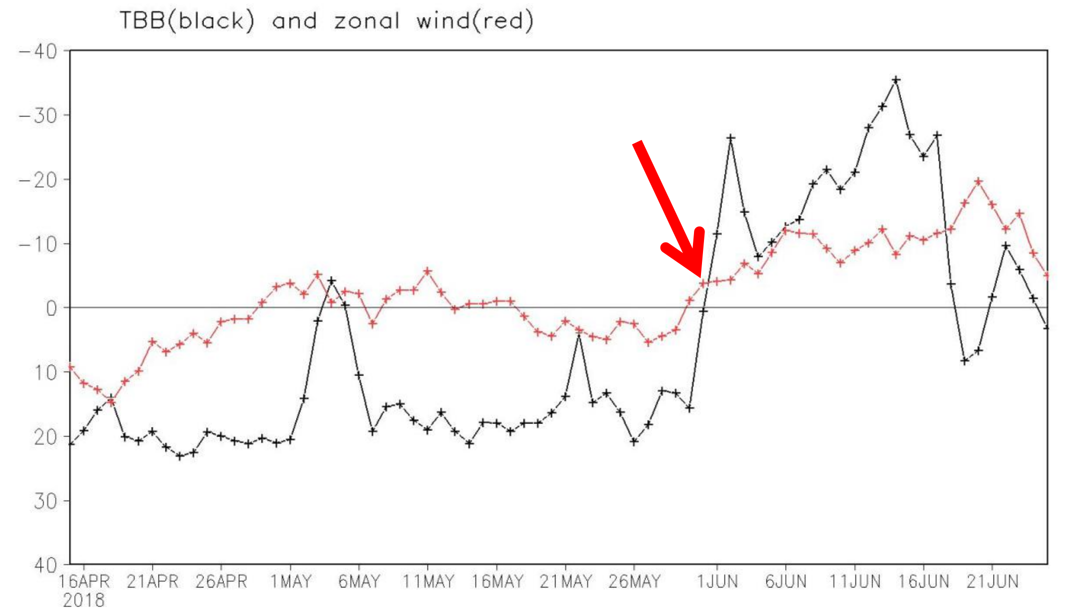


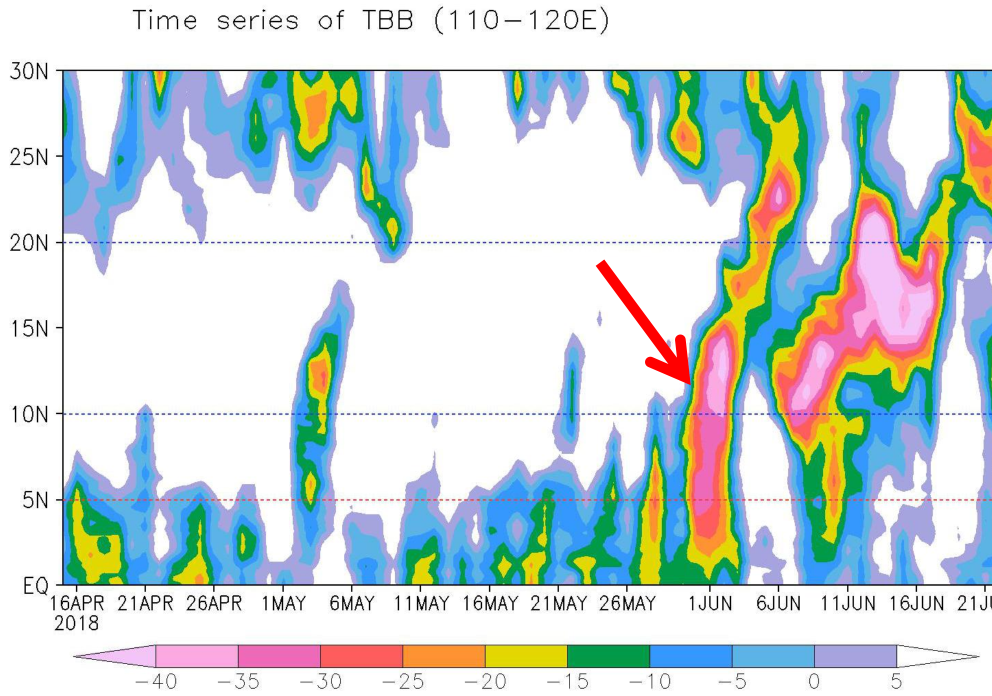
Five day averaged TBB from June 16 to 20, 2016



Time serial of daily averaged TBB (110-120E)

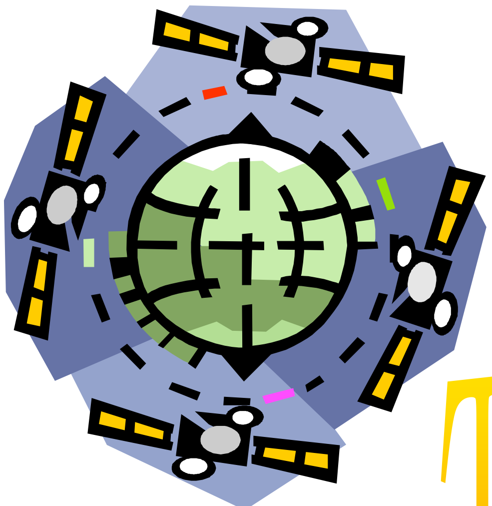
The SCS Summer Monsoon monitoring in 2018





Summary--2

- the regional averaged upper level AMV derived form IR3 channel can be used in monsoon onset monitoring.
- The regional averaged TBB can be used in monitoring the convection activity and break off during then SCS summer monsoon season.



...... Stop Here

Thank you!