Microwave-TC intensity estimation

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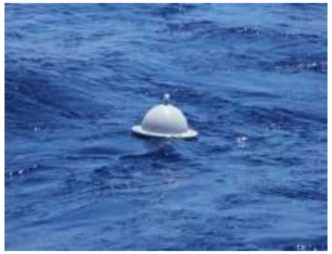
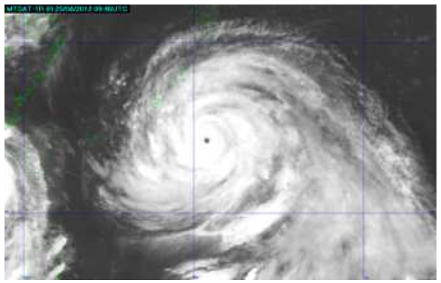
Introduction

Satellite observations are essential for analysis of tropical cyclone (TC) intensity, such as Minimum Sea Level Pressure (MSLP) and Maximum Sustained Wind (MSW), particularly where in situ observations are sparse.

In situ observations : Low spatial resolution



Satellite observations: Wide coverage, high temporal resolution (for MTSAT)



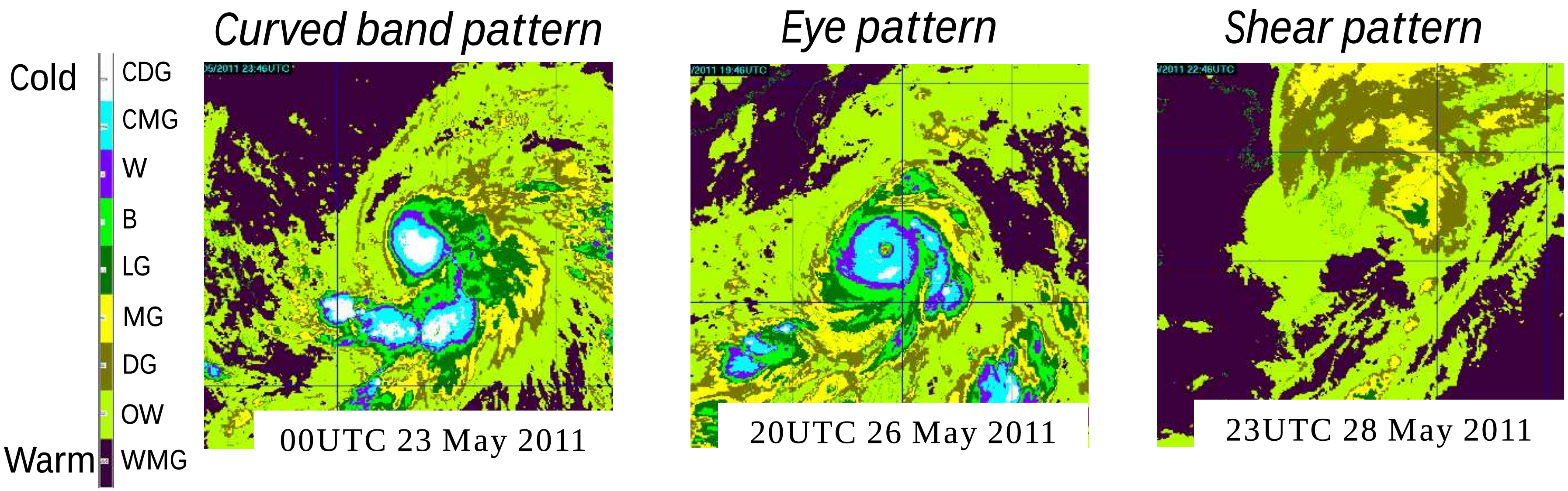
TC intensity analysis
(MSLP, MSW)

Use applications:

- Early analysis
- Best track analysis
- Creation of TC bogus vortex for NWP initial analysis

Dvorak technique
(based on Infrared image from geostationary satellite)

:A primary method based on satellite observation

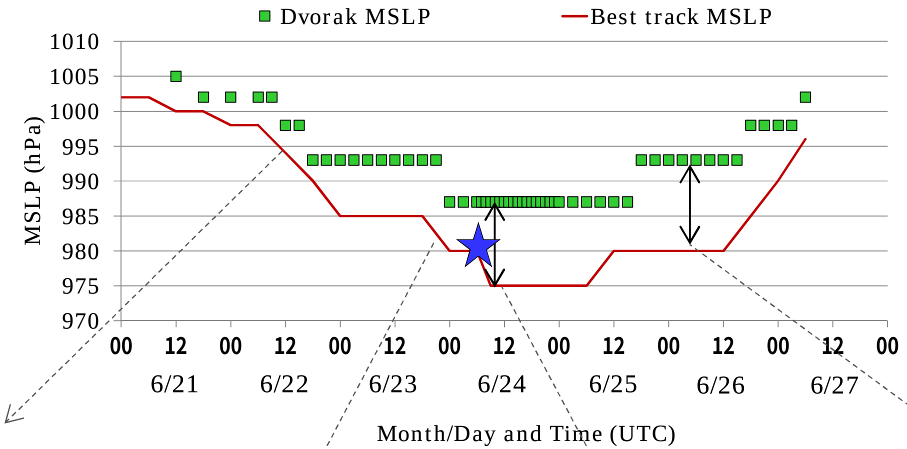


Brightness temperature (TB) of MTSAT infrared channel for TC Songda (1102)
:Cloud top temperature

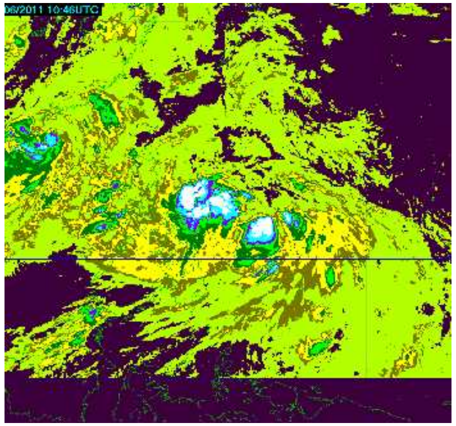
Dvorak technique requires analysis skills based on enough experience !

However, Dvorak technique has some weak points.

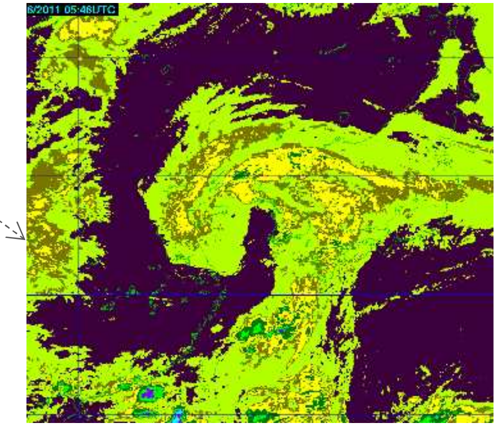
TC Meari (1105)



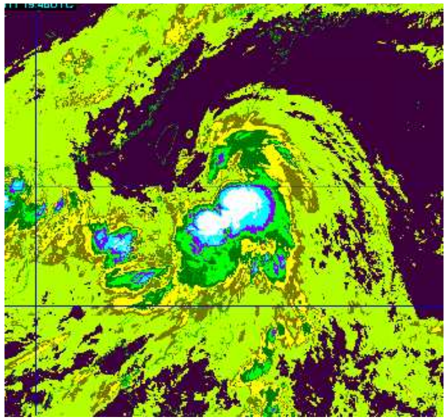
Jun.22 11UTC
(CB cluster)



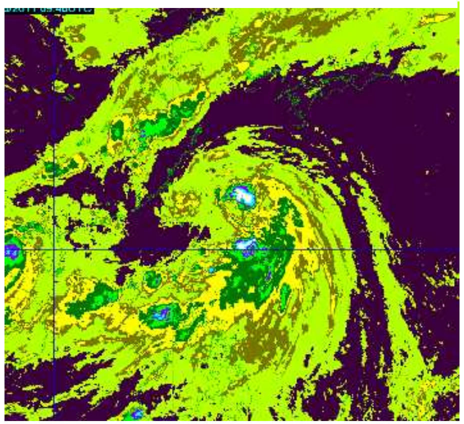
Jun.26 06UTC
(Shear/LCV)



Jun.23 20UTC
(CB cluster)

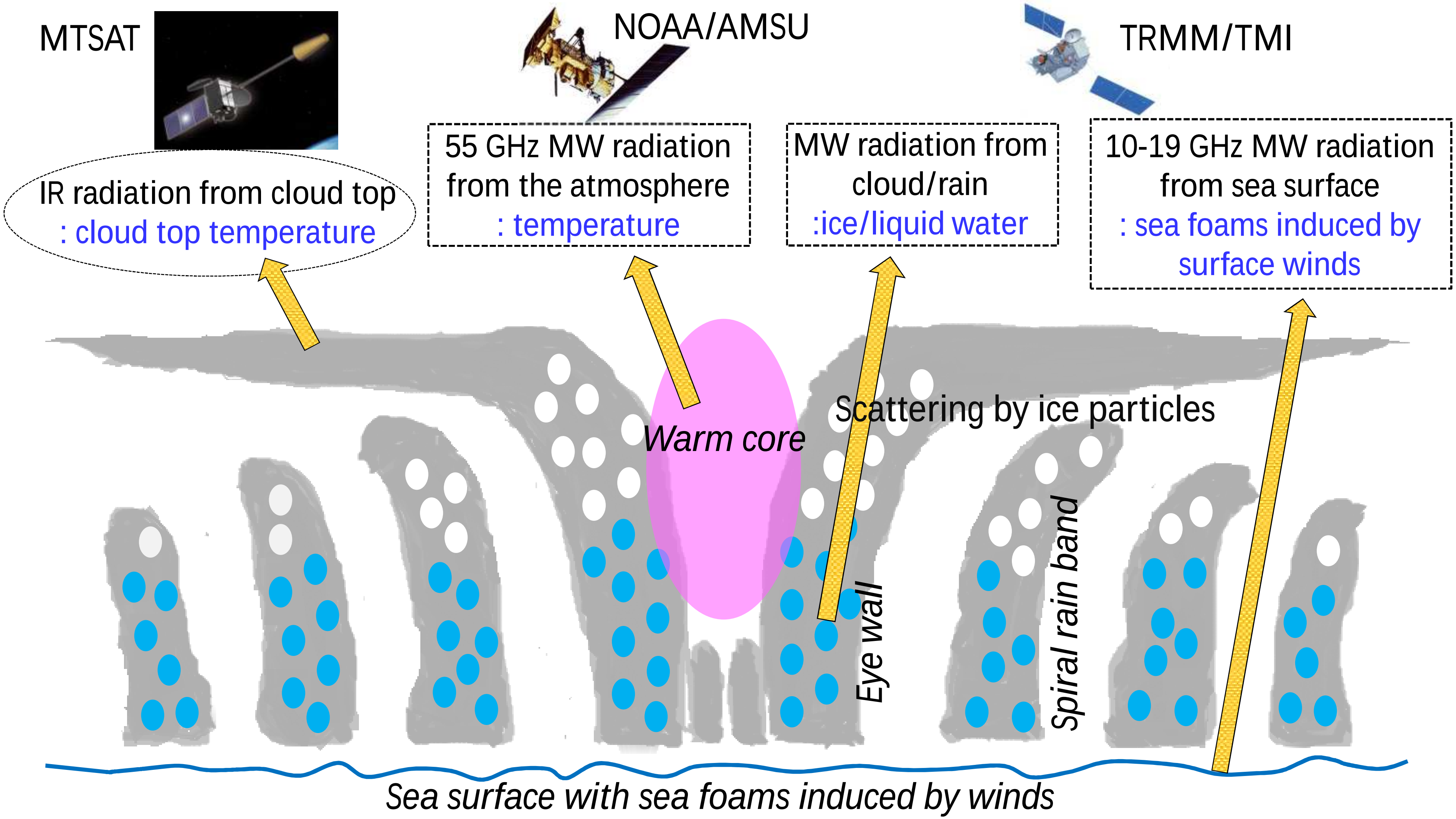


Jun.24 10UTC
(Curved band)



★ in situ observation at Miyako-jima: 982 hPa

Satellite microwave sensor can observe TC internal structure !

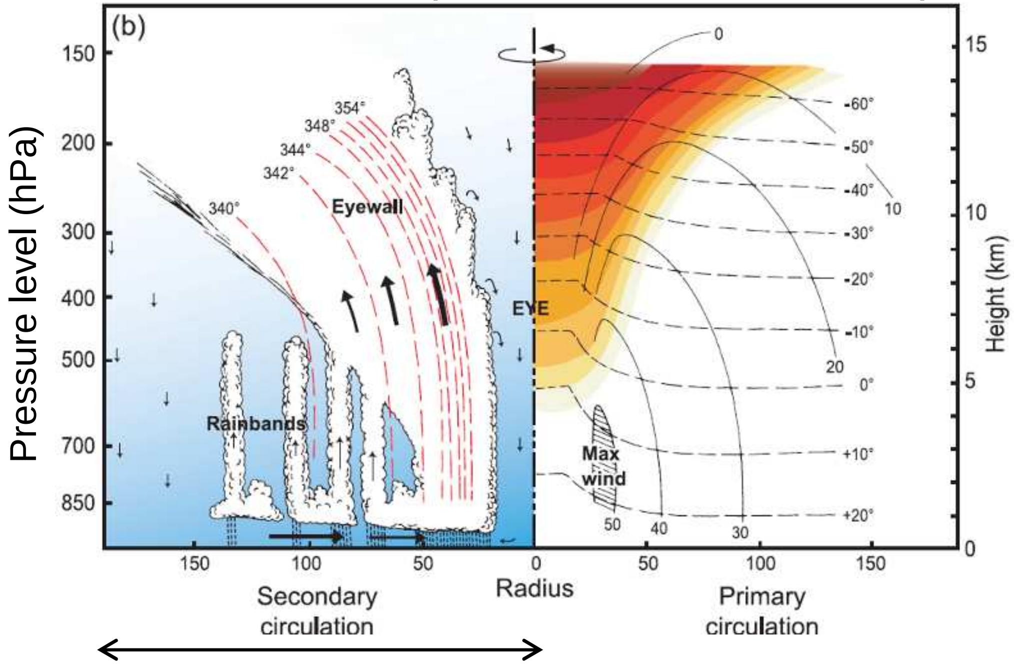


gray : clouds, white: ice cloud/rain, light blue : liquid rain

Estimation of TC maximum sustained wind (MSW) using TRMM Microwave Imager (TMI) data

Basic TC structure seen in rain and wind distributions

Radial cross section through an idealized, axially symmetric hurricane in TC inner core (Wallace and Hobbs 2006)



Inner core (radius < 100〜200 km)

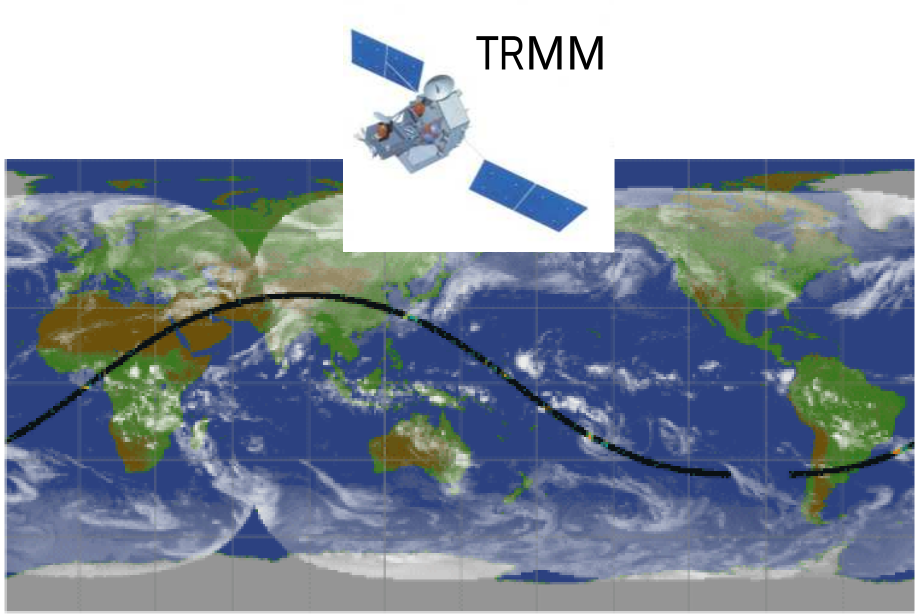
Convergence near the surface increases due to increase of inflow with tangential wind intensified,

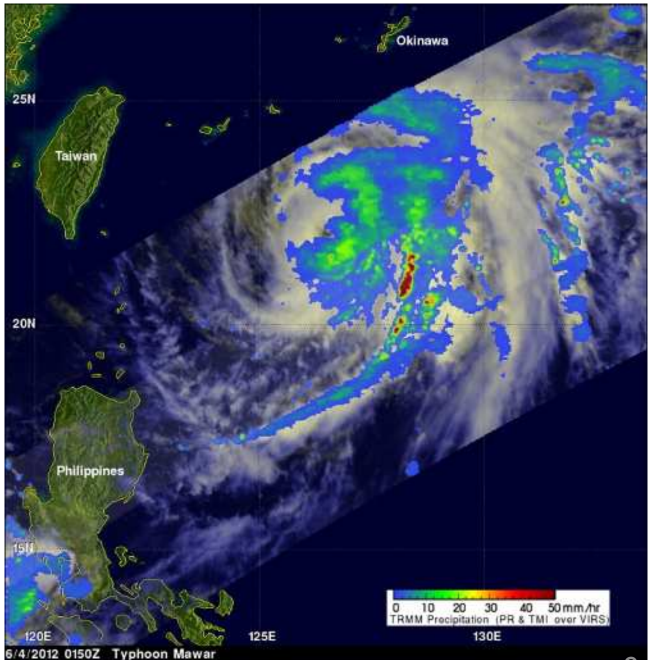
Cloud and rain water increases as eye walls and rain bands are formed.

TRMM/TMI observation

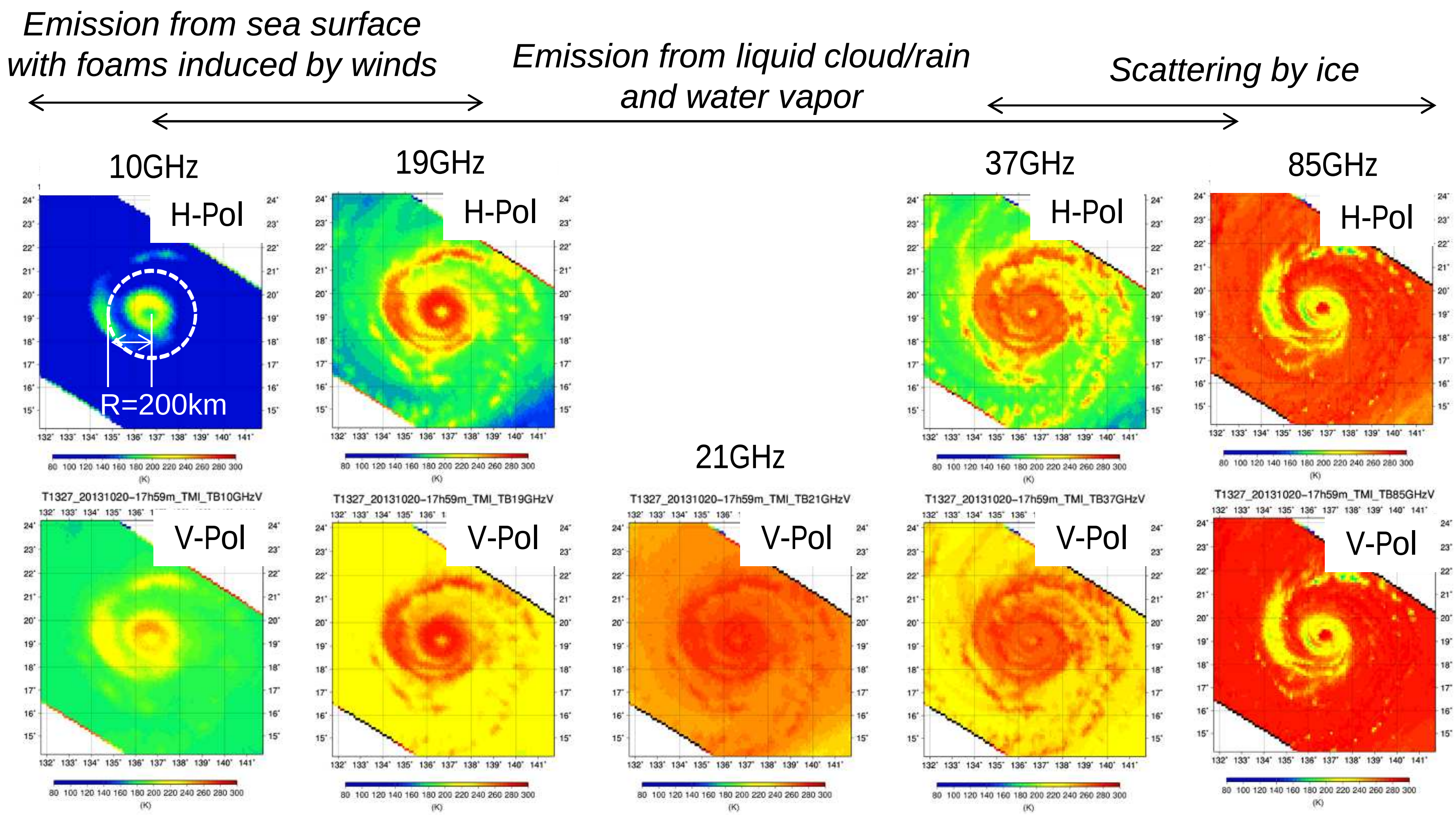
TMI microwave imager (November 1997～)

- Onboard TRMM for observing rain and sea surface over the tropical region.
- Channel frequencies (GHz) : 10.7(V/H), 19.35(V/H), 21.3(V), 37(V/H) and 85.5(V/H).
- Spatial resolution of data is 38.3 km (10.7GHz)～4.4 km (85.5GHz).
- 3 observations per day at maximum available (depending on TC location)





TMI can obtain information on ice/liquid rain and sea surface.



TMI TB images for TC Francisco (1327) at 1759UTC on 20 Oct 2013

TC maximum sustained wind estimation (MSW) method using TMI observation (TMI technique)

- TMI technique had been developed by MRI/JMA in 2004-2011 and has been validated in 2012-2013.

- TMI technique estimates MSW using information on ice/liquid rain distribution and sea foams induced by surface winds in TC inner core (radius < 2 degrees) obtained from TMI observation.

- MSW is estimated by using a multiple-regression equation where TB parameters computed using TMI TBs are used as the input variables. The TB parameters are also used for recognition of TB image pattern.

- The multiple-regression equations for MSW estimation were derived for respective TB image patterns from TMI observations in reference to JMA best-track data for TCs during 1998-2008.

Algorithm of TMI technique for MSW estimation

(Step 1) TB parameters (max, average, min etc. in the defined domains) for TMI channels are computed.

(Step 2) TB image pattern of TC inner core (radius < 2 degrees) was determined (out of 10 patterns) using TB parameters.

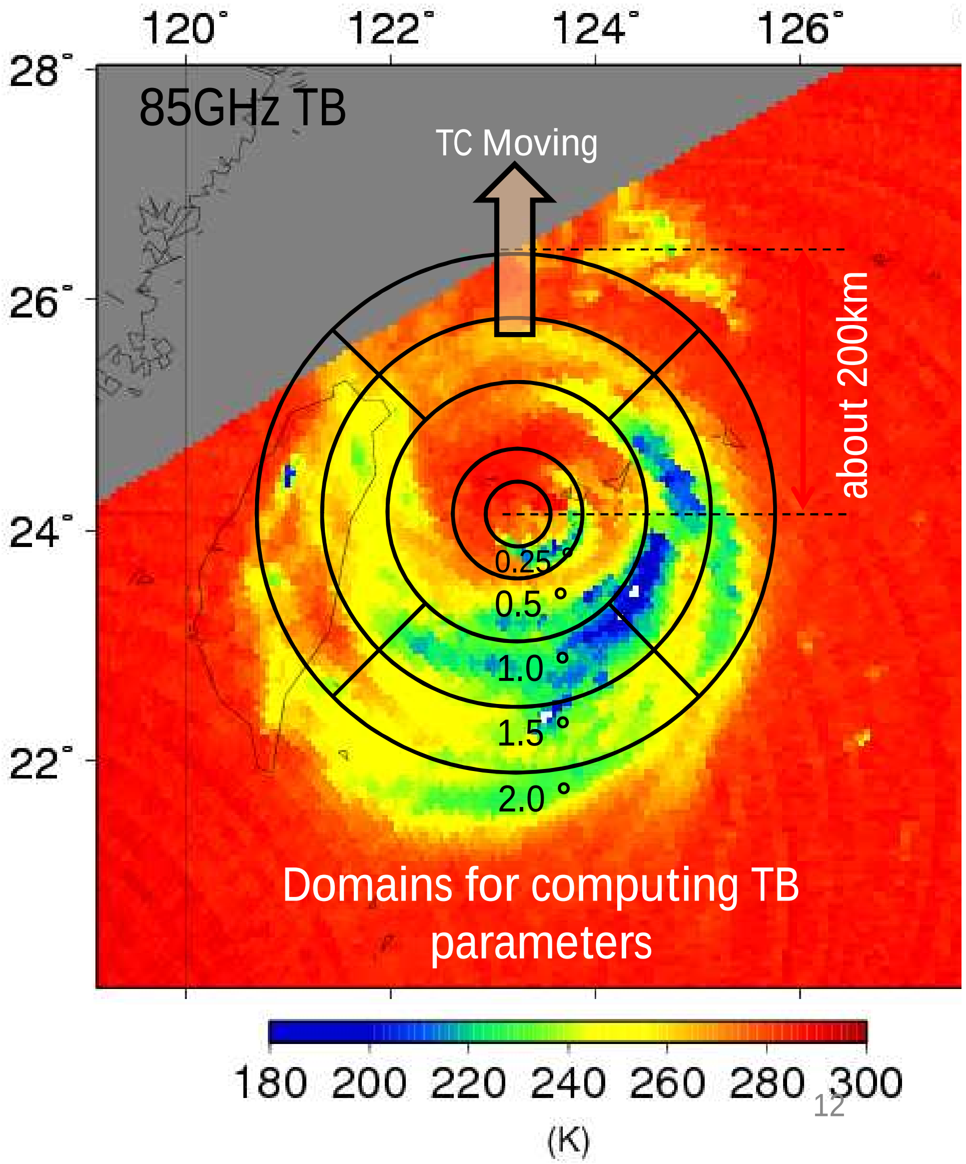
(Step 3) MSW is estimated by using a multiple-regression equation for each TB image pattern.

Regression equation for MSW estimation:

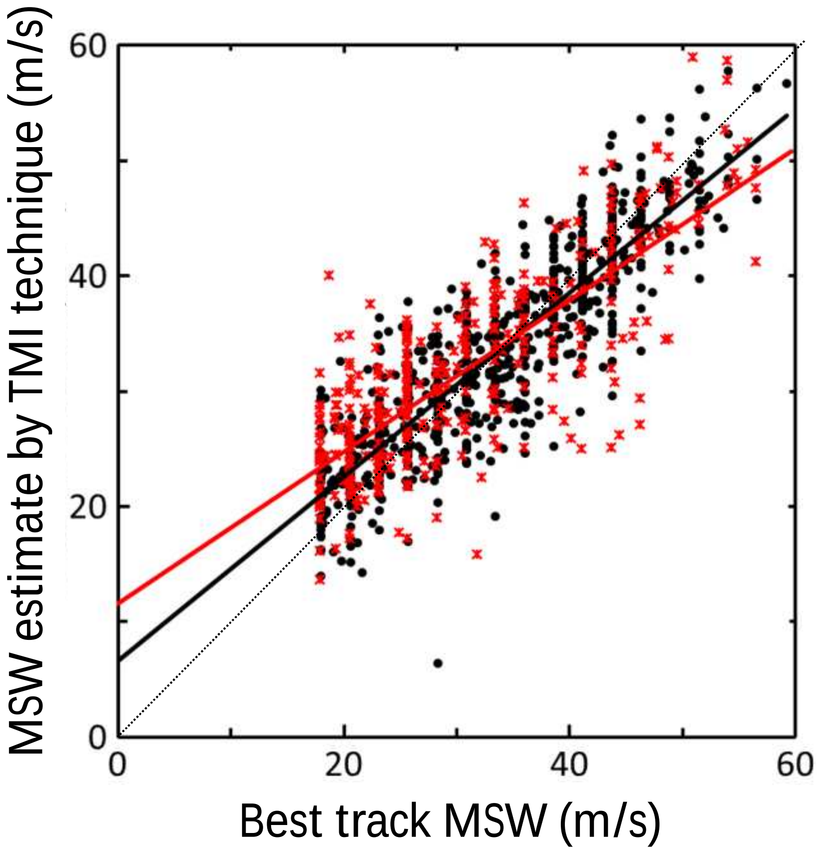
MSW = A0 + **Σ** {A(n) x TBparam(n)}

TBparam(n): TB parameters highly correlated to MSW

n = 1 to 7



Validation of MSW estimates by TMI technique with reference to the best-track data

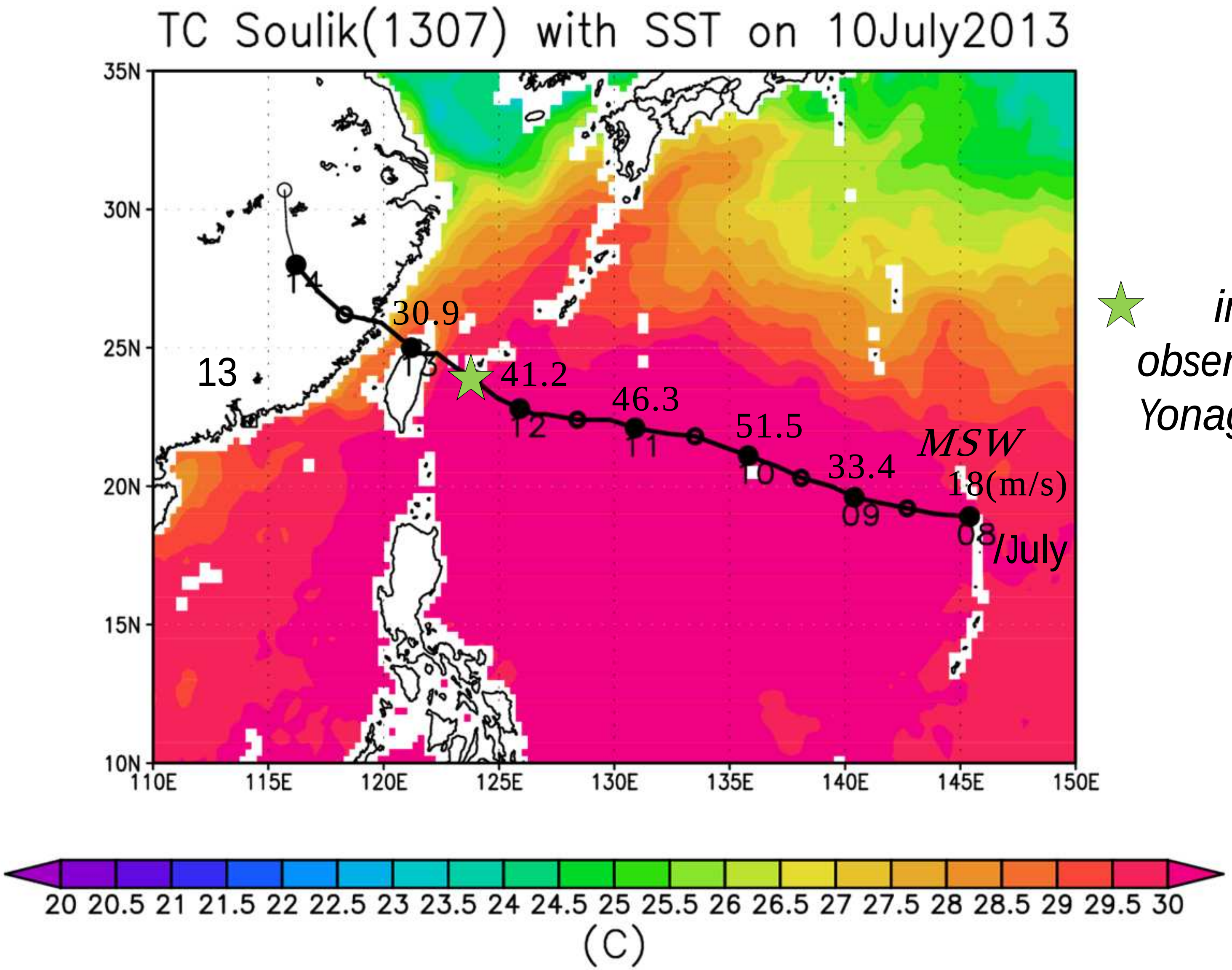


Black : Observations for TCs in 1998-2008
(used for deriving the estimation equation)
Number = 749

Red : Observations for TCs in 2009-2012
(independent on the estimation equation)
Number = 341
RMSE = 6.26 m/s
BIAS = 0.99 m/s

Relatively large estimation errors come from
(i) Inadequate use of TB parameters for estimation during TC formation stage
(ii) Determination error of TC center position

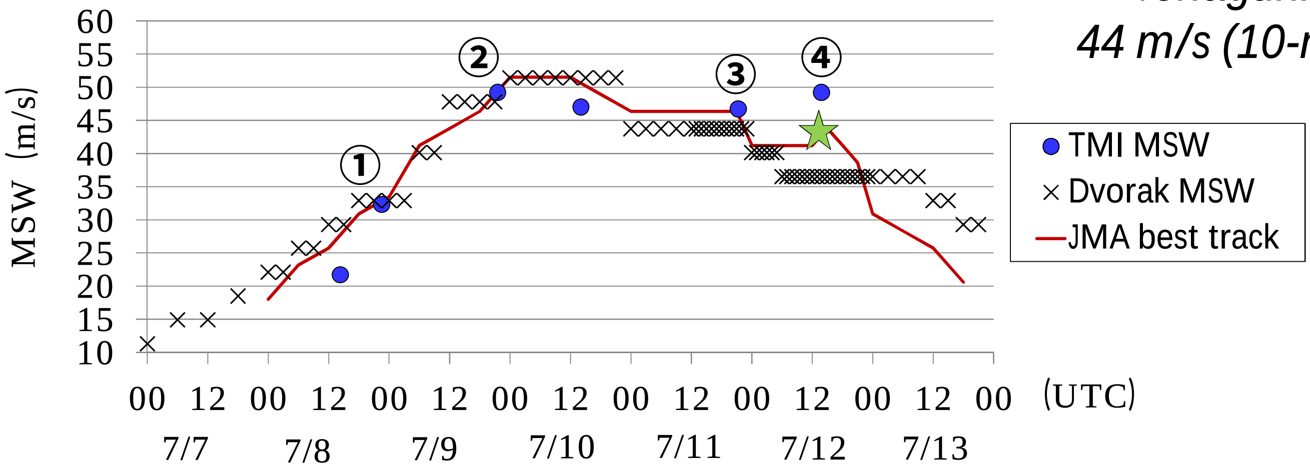
TC Soulik (1307)



★ *in situ observation at Yonaguni-jima*

TC Soulik (1307)

in situ observation at Yonaguni-jima: 44 m/s (10-min ave.)

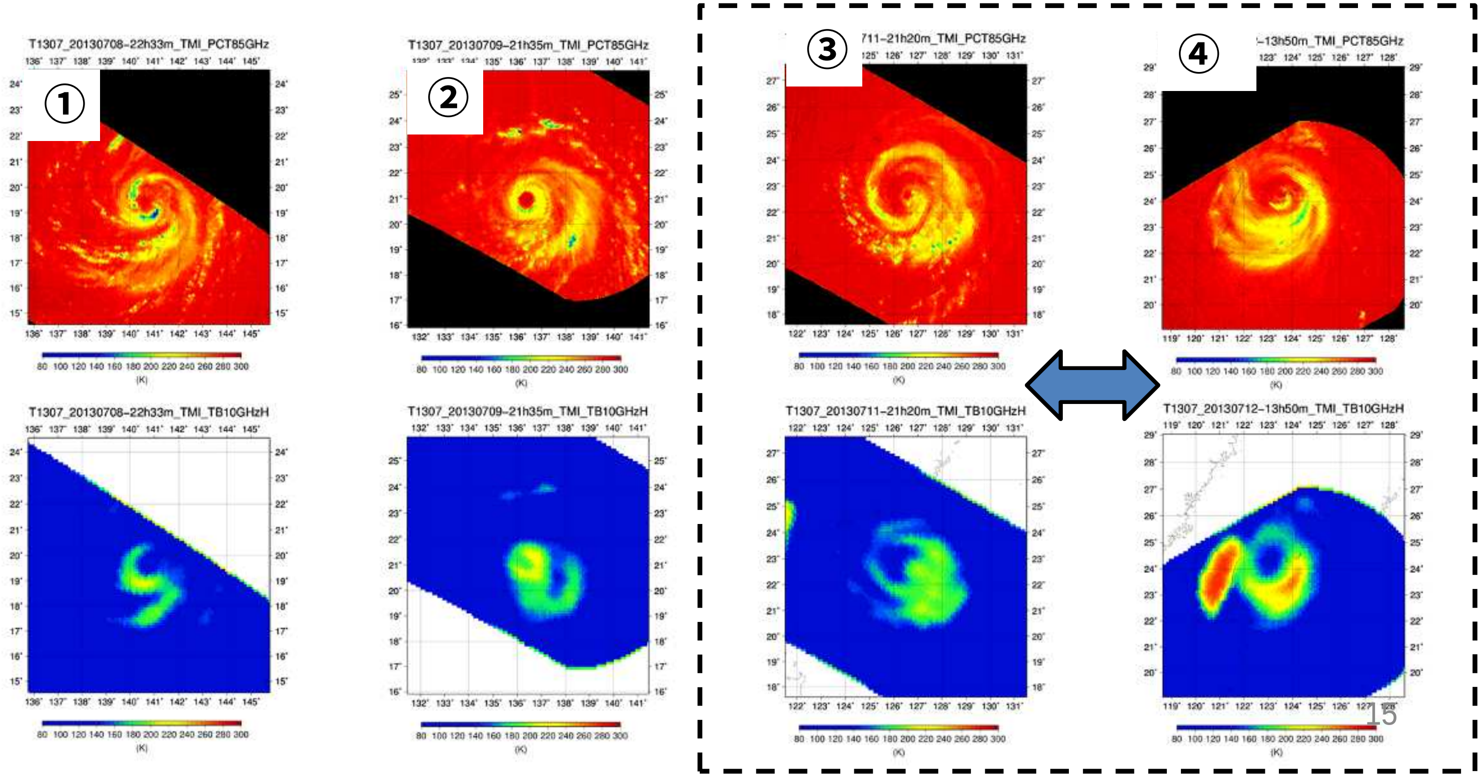


85GHz (PCT)

ice cloud/rain

10GHz (H)

liquid rain and sea foams



Summary and conclusion on MSW estimation by TMI technique

- TMI technique estimates MSW based on TB parameters computed using TMI TBs in TC inner core.

- Validation of the MSW estimates to best track data for TCs in 2009-2012 showed that RMSE is 6.26 m/s (comparable to Dvorak technique).

- It is essential to find in which situation MSW estimate by TMI technique could support operational TC intensity analysis, in addition to improvements of the algorithm.

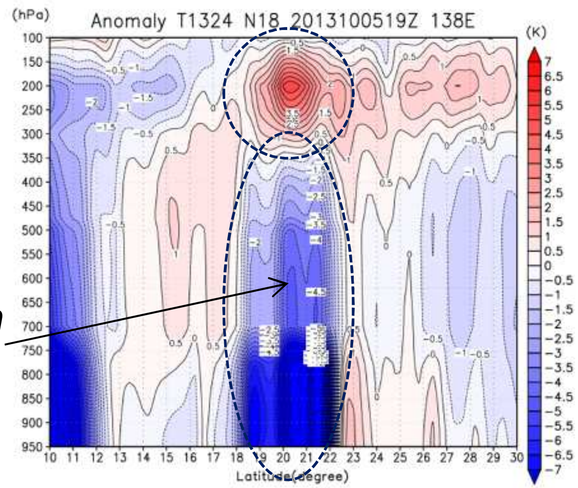
Estimation of TC Minimum Sea Level Pressure (MSLP) based on warm core intensity observed by Advanced Microwave sounding Unit-A (AMSU-A)

What is warm core ?

- Warm core is formed near TC center, with a positive temperature anomaly to the environment.
- Warm core is a characteristic feature to identify TC intensity and TC size.

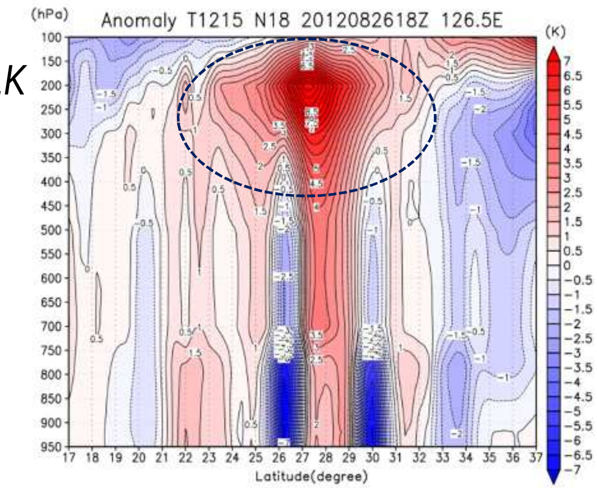
Anomaly～5K at 200 hPa

TB attenuation of microwave



Temperature anomaly by AMSU-A for TC Danas (1324)
MSLP=975 hPa, MSW=31 m/s,
Shortest radius of 30knot winds (R30)= 222km

Anomaly～11K at 200 hPa



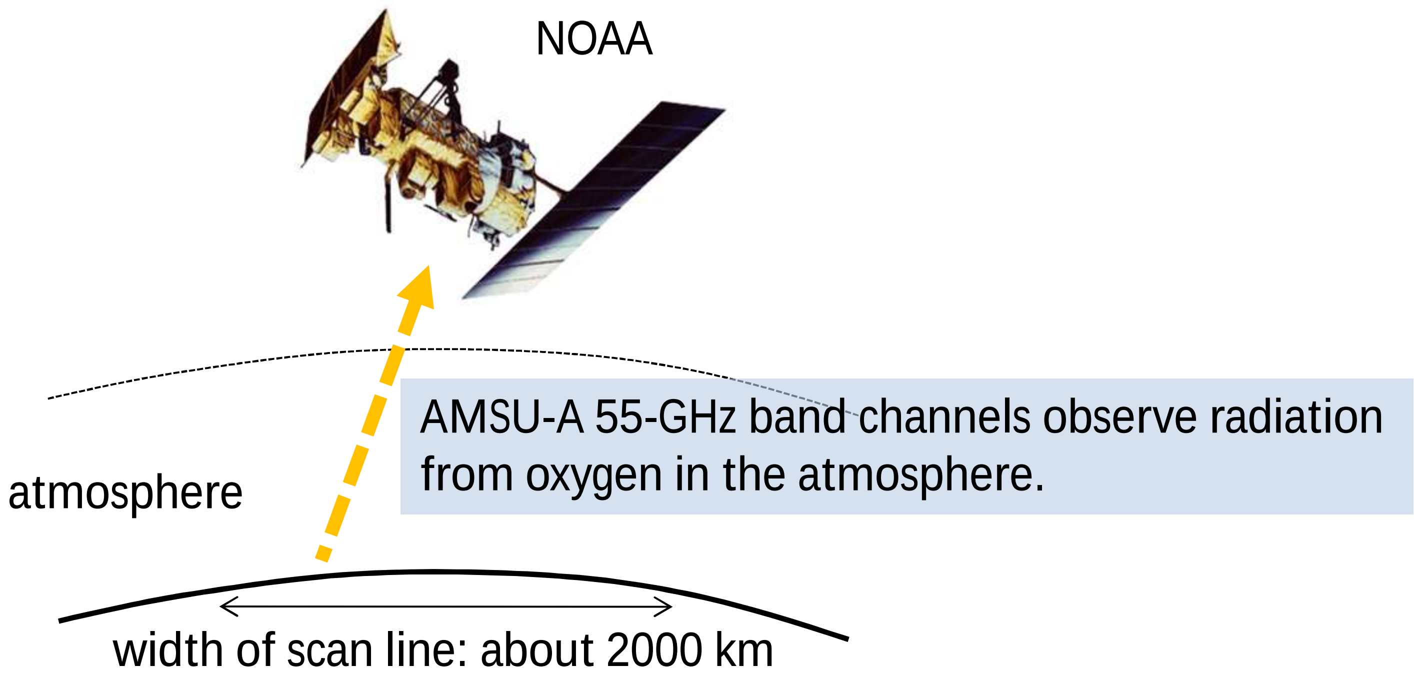
TC Bolaven (1215)
MSLP=940 hPa, MSW=41 m/s,
R30 = 555km

Warm air	⟷	*Low surface pressure*
Large (small) warm core	⟷	*Large (small) TC size*

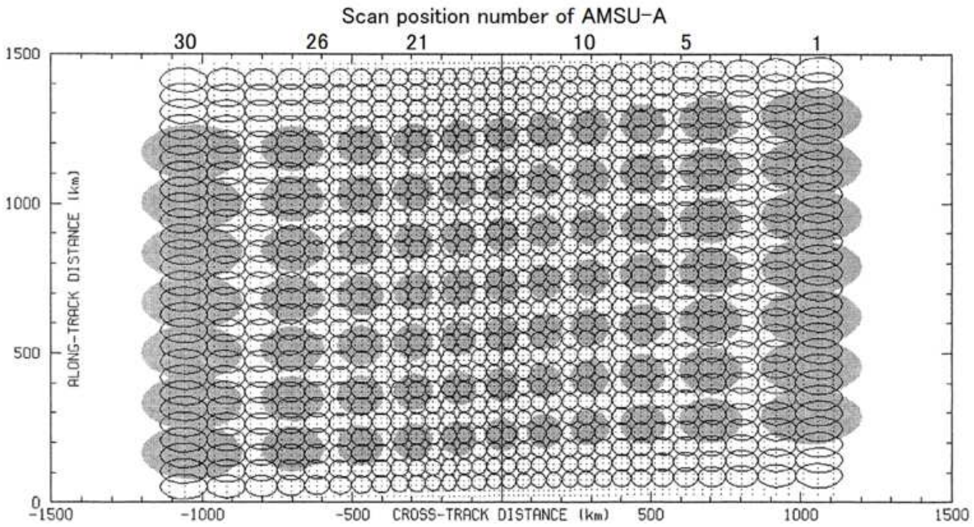
Advanced Microwave Sounding Unit-A (AMSU-A)

AMSU-A

- is onboard NOAA and METOP series polar orbital satellites.
- has been operated since 1998 (NOAA-15 is the first satellite for AMSU).
- observes twice per day at maximum (5 satellites available)
- consists of twelve channels (Ch3 - Ch14) for atmospheric temperature sounding.

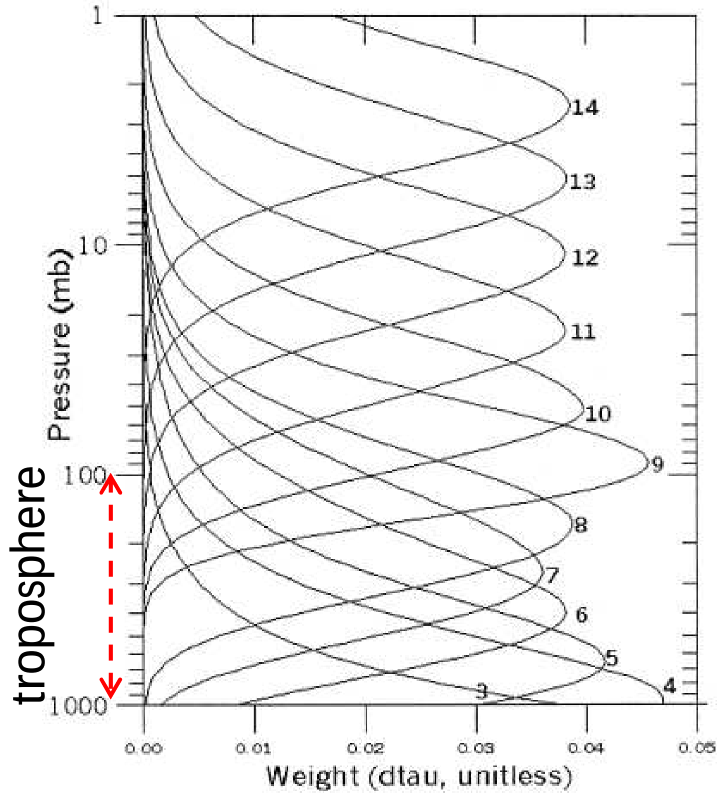


Field of View (FOV) of AMSU-A channels (open ellipses) (*kidder et al. 2000*)



AMSU-A FOV size: 48km - 150 km

Weighting functions of AMSU-A channels (*Kidder et al. 2000*)

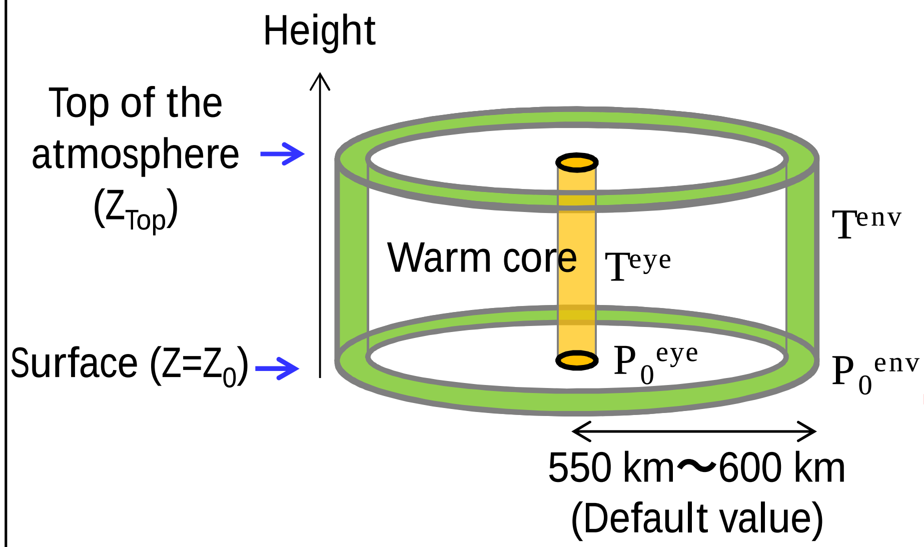


- AMSU-A channels for observing the troposphere are Ch4 (900 hPa level), Ch5 (600 hPa), Ch6 (400 hPa), Ch7 (250 hPa) and Ch8 (180 hPa).
- TBs for Ch4 and Ch5 for observing the lower troposphere tend to be attenuated significantly by rain near TC center.

MSLP estimation method based on TC warm core intensity observed by AMSU-A (AMSU technique)

- AMSU technique was developed by MRI/JMA in collaboration with RSMC Tokyo – Typhoon Center in 2011-2012.
- This technique estimates TC Minimum Sea Level Pressure (MSLP) using AMSU-A brightness temperature (TB) anomaly corresponding to TC warm core intensity.
- A regression equation for MSLP estimation was derived using AMSU-A observations in reference to JMA best-track data for 22 TCs for 2008.

Basis of MSLP estimation from temperature anomaly corresponding to TC warm core



Hydrostatic equilibrium theory：

$$\log\left(\frac{P_0}{P_{Top}}\right) = \frac{g}{R}\int_{Z_0}^{Z_{Top}} \frac{dZ}{T(Z)}$$

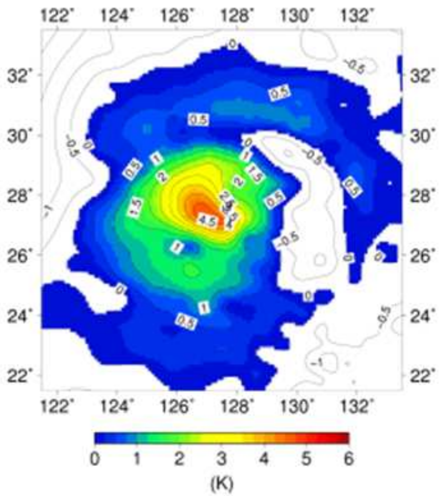
$$P_o^{eye} \cong P_0^{env}[1 - Constant \times (< T^{eye} > - < T^{env} >)]$$

MSLP

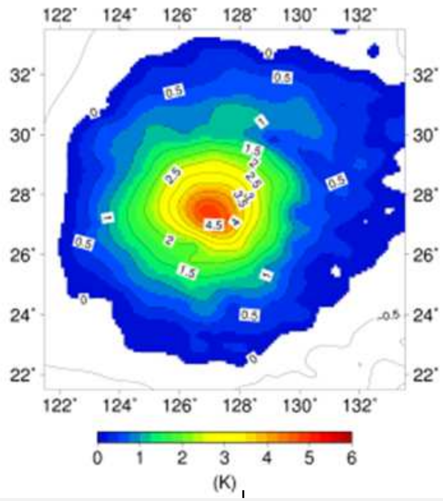
MSLP	≅	Environmental surface pressure
	−	Surface pressure decrease equivalent to temperature anomaly at TC center

Warm core intensity used for MSLP estimation

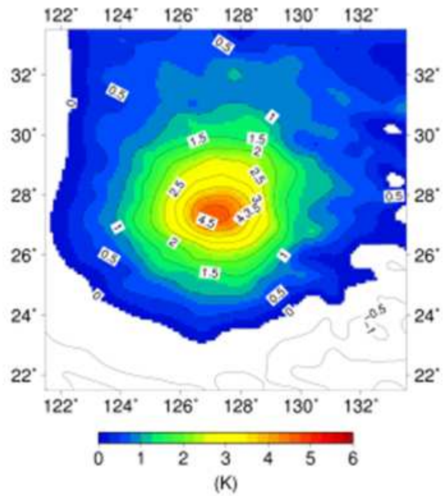
TB anomaly for
Ch6 (〜400 hPa level)



TB anomaly for
Ch7 (〜250 hPa level)



TB anomaly for
Ch8 (〜180 hPa level)



Max TB anomaly

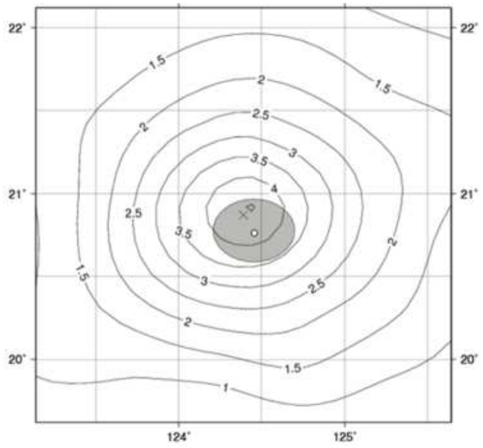
Max TB anomaly

Max TB anomaly

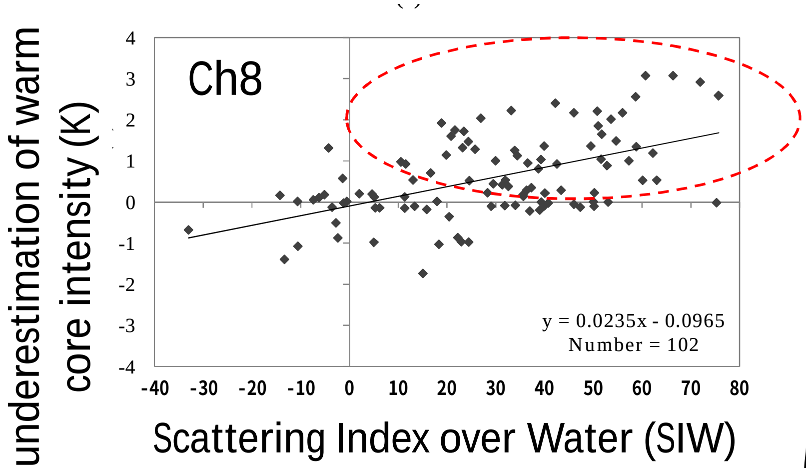
Maximum
(defined as warm core intensity)

Correction of warm core intensity retrieval errors and MSLP estimation

Error due to low spatial resolution (48 〜150 km) of AMSU-A observation



TB attenuation error due to ice particles

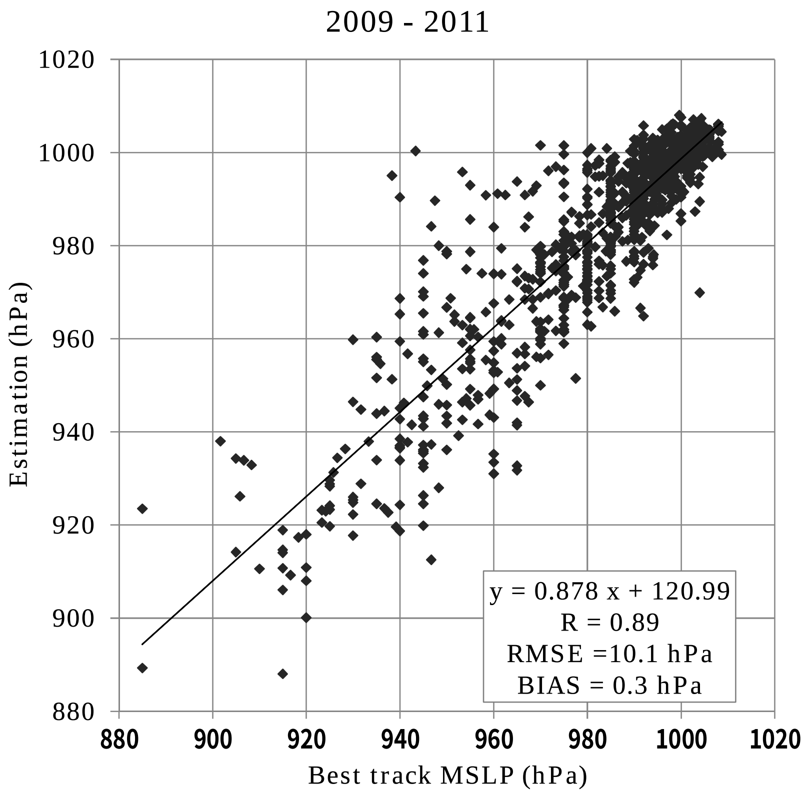


These warm core intensity retrieval errors are corrected by developed schemes.

MSLP estimation equation derived using AMSU-A observations with reference to JMA best track data for TCs in 2008 :

MSLP = SLOPE×(warm core intensity) + OFFSET

Validation of AMSU MSLPs to JMA best-track data for TCs during 2009-2011



Number of observations: 1029
RMSE : 10.1 hPa
BIAS: 0.3 hPa

Statistical validation revealed several characteristics of AMSU MSLPs:

1. Better quality of AMSU MSLPs for large TCs than compact TCs, suggesting a difficulty of observing small warm core.
2. Quality degrading of AMSU MSLPs due to too large microwave scattering near TC center.
3. Superiority of AMSU MSLPs to Dvorak MSLPs when TC is not compact and TC cloud pattern is “Curved band” or “Shear/LCV”.

Characteristics of MSLP estimates by AMSU technique

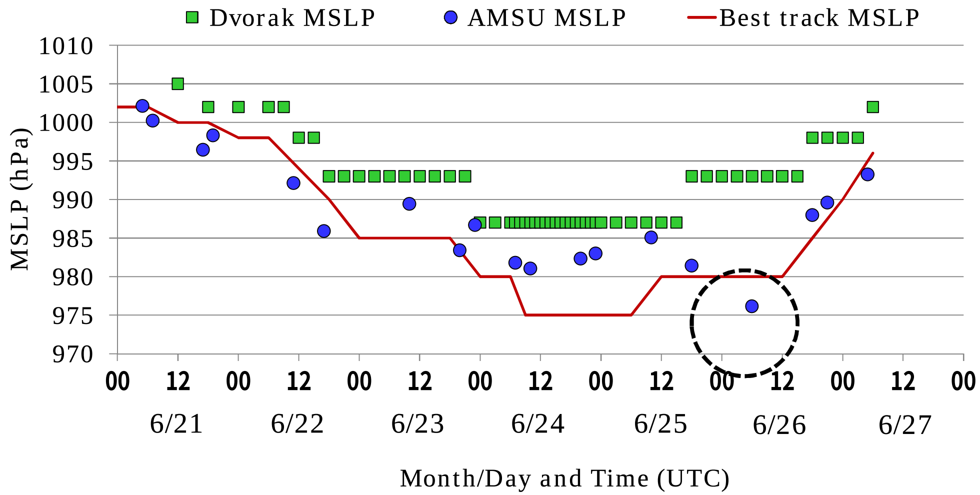
- Characteristics of MSLP estimates by AMSU technique (AMSU MSLP) are shown in comparison with JMA best track data and MSLP estimates by Dvorak technique (Dvorak MSLP) for three typical cases of TCs during 2009-2011.

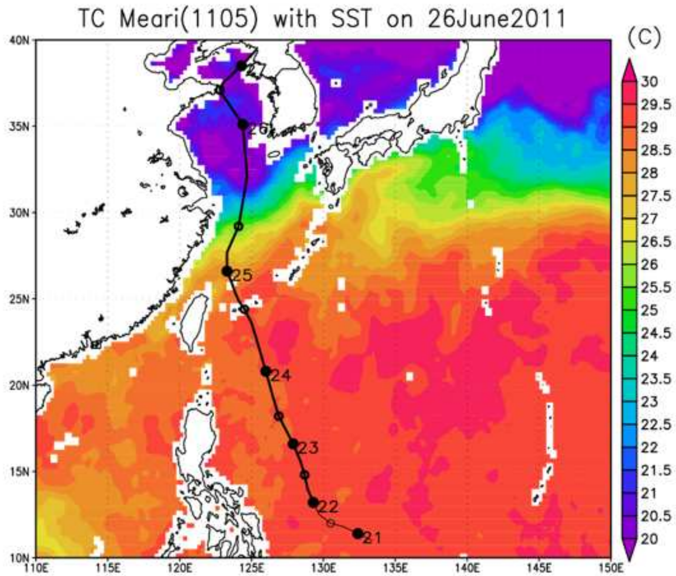
- For TCs during 2009-2011, JMA best track data depends on Dvorak MSLP, while it does not depend on AMSU MSLP.

- Shortest radius of 30 knot winds (R30) from best track data is used as TC size related to warm core size. Average R30 value between 2000-2011 for each MSLP is also used as the criterion.

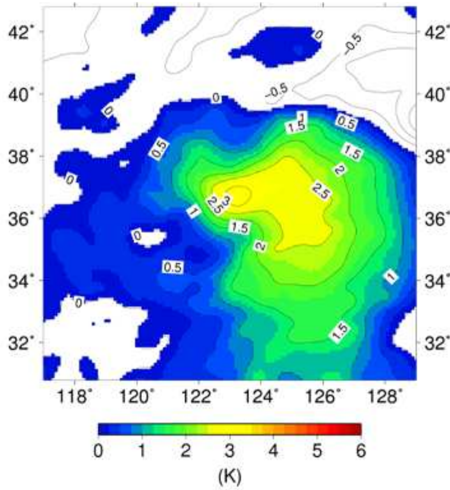
TC Meari (1105)

average R30 (261 km) < R30 of Meari (370 km)
for MSLP of 975 hPa

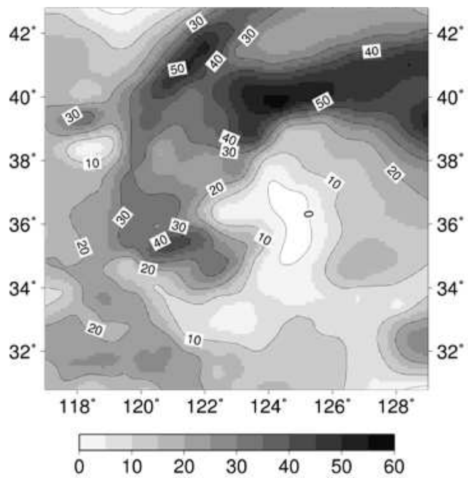




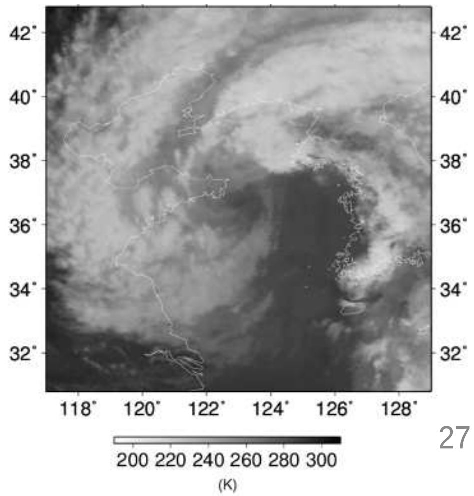
AMSU-A TB anomaly (Ch6): ～400 hPa



MW scattering (SIW)

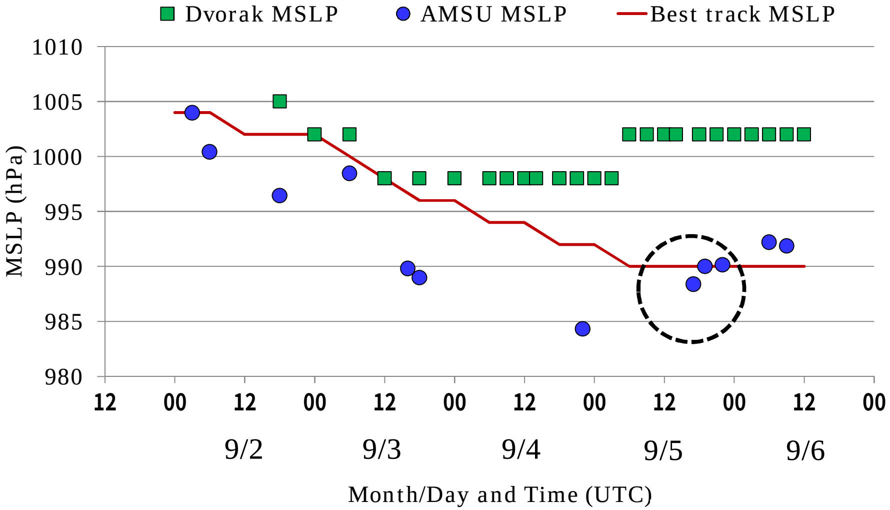


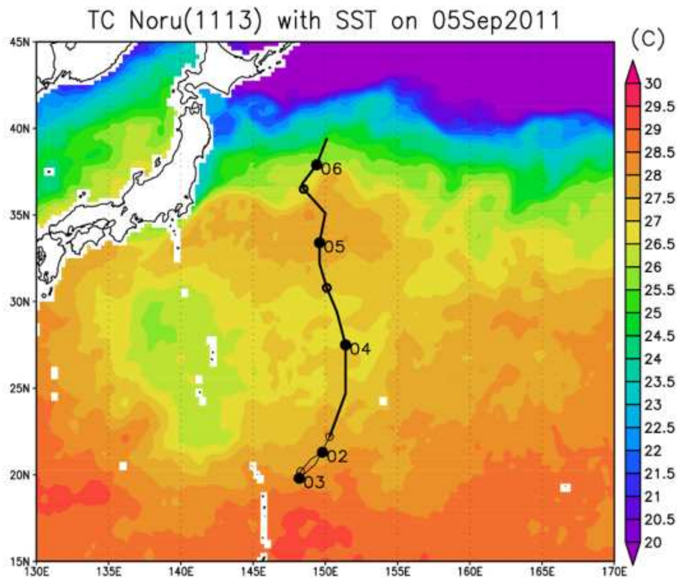
IR TB; Shear pattern



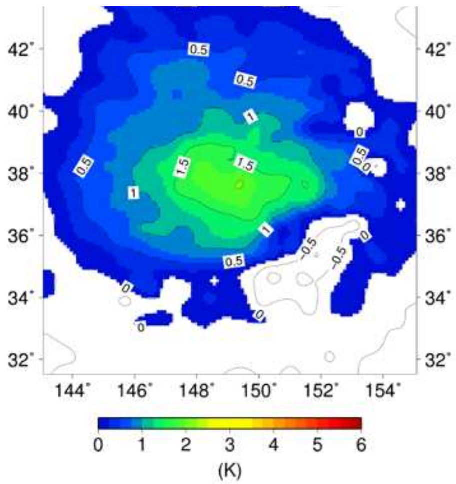
TC Noru (1113)

average R30 (197 km) < R30 of Noru (370 km)
for MSLP of 990 hPa

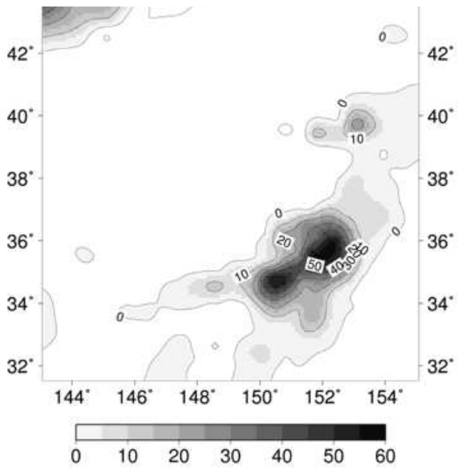




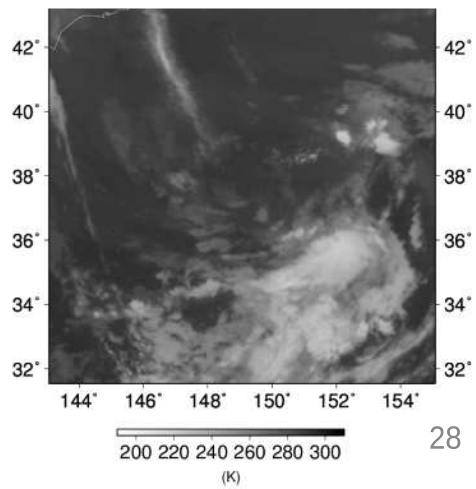
AMSU-A TB anomaly (Ch6): ～400 hPa



MW scattering (SIW)

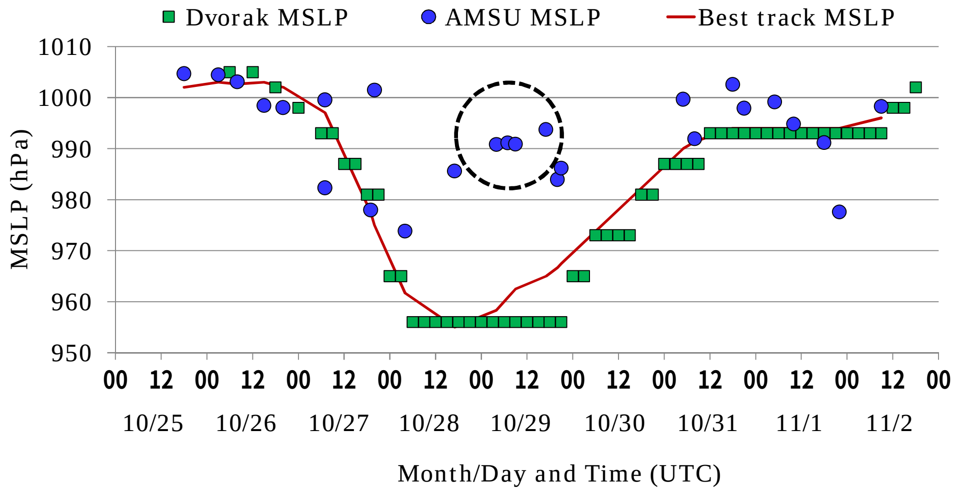


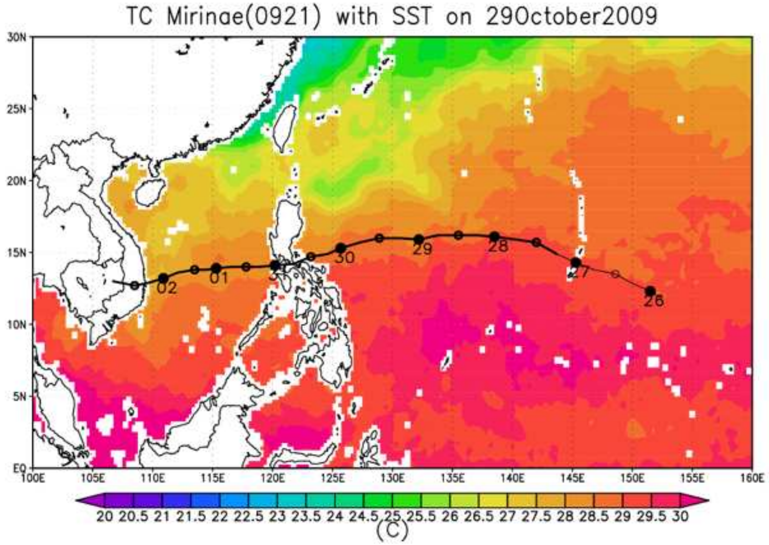
IR TB; Shear/LCV



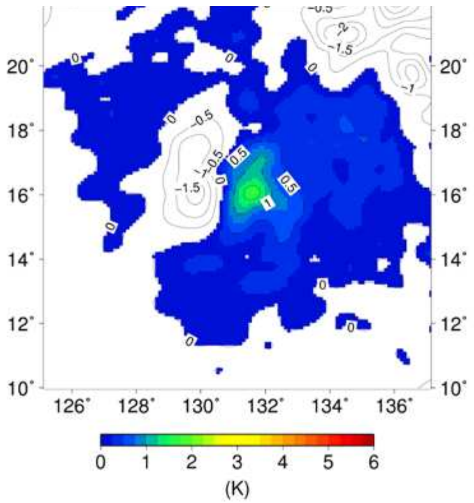
TC Mirinae (0921)

average R30 (354 km) > R30 of Mirinae (148 km)
for MSLP of 960 hPa

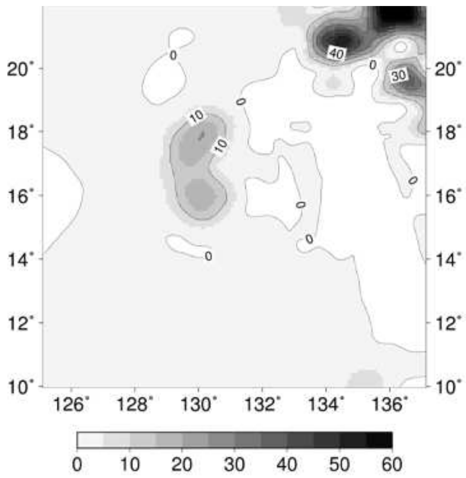




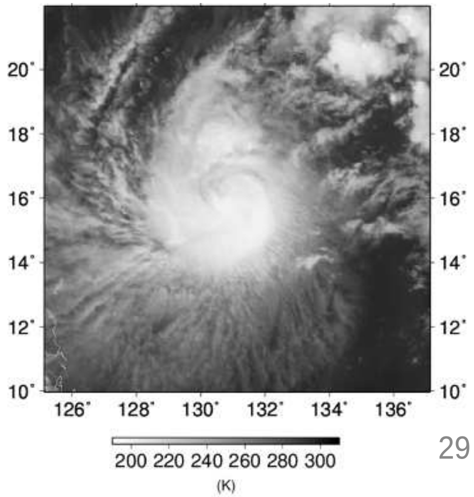
AMSU-A TB anomaly (Ch6): ～400 hPa



MW scattering (SIW)



IR TB



Summary and conclusion on MSLP estimation by AMSU technique

- AMSU technique estimates MSLP using TC warm core intensity as observed by AMSU-A.
- MSLP estimates by AMSU technique tended to be better than those by Dvorak technique for incompact TCs with specific TC cloud patterns (Curved band or Shear/LCV).
- AMSU MSLP is expected to support operational MSLP analysis when in situ data is not available and the estimation accuracy of Dvorak technique is low.

Future plan for Microwave-TC intensity estimation

RSMC Tokyo – Typhoon center began to use TC intensity estimates by AMSU and TMI techniques as references for the operational TC intensity analysis in 2013.

Future works for further contribution of the estimation to operational TC intensity analysis are:

- Improvements to the current algorithms
- Use of satellite observations other than AMSU-A and TMI for TC intensity estimation

  SSMIS microwave imager/sounder (DMSP)

  AMSR2 microwave imager (GCOM-W1)

  ATMS microwave sounder (NPP)

Thank you