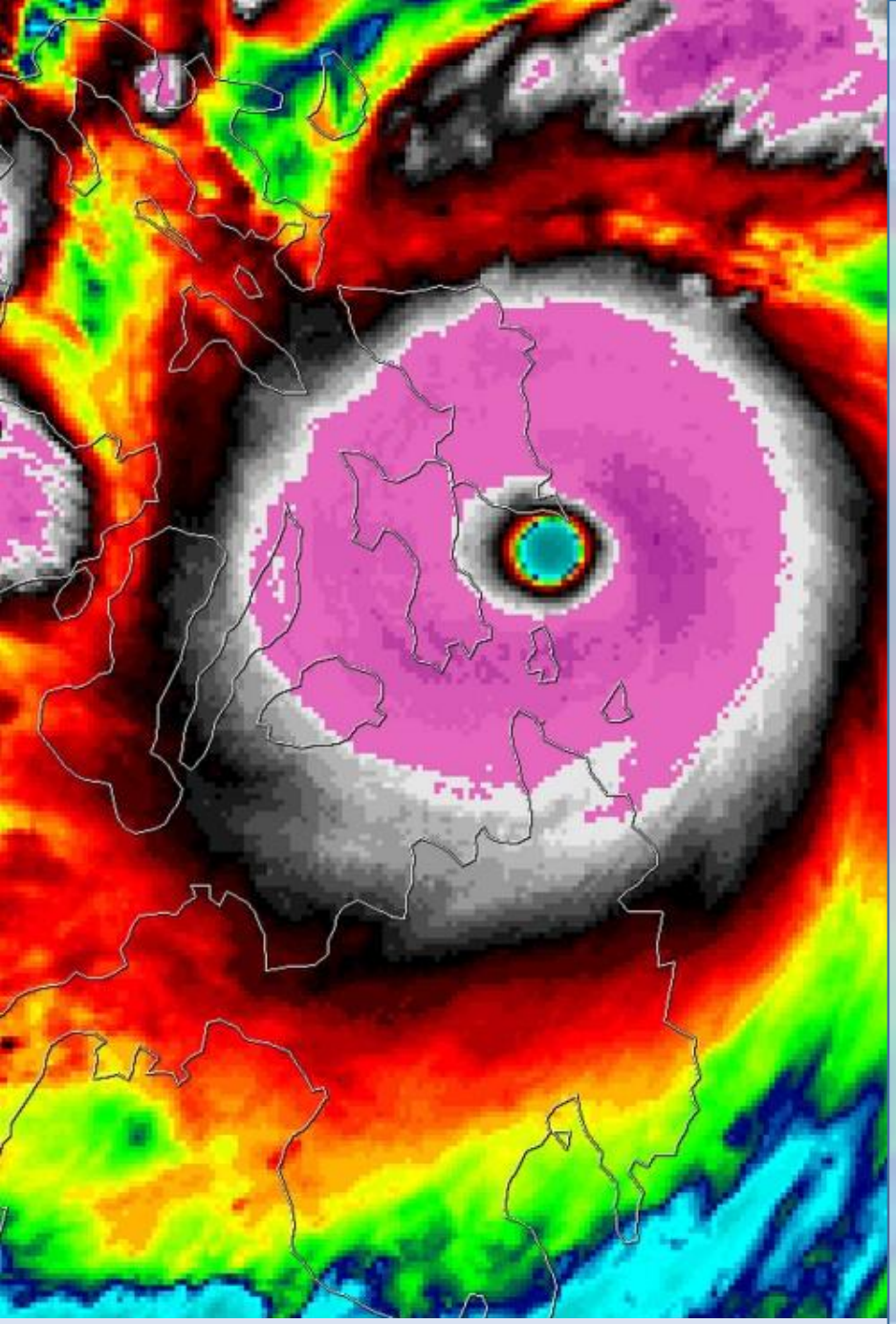

Super Typhoon Haiyan on 7 Nov. 2013 images from the Korean COMS-1 satellite.
(Source: CIMSS Satellite Blog)

Development of Objective Forecast Guidance on Rapid Intensification of Tropical Cyclones over the Western North Pacific

T C Lee, H F Tam and C W Choy
Hong Kong Observatory

49th Session of Typhoon Committee
21-24 Feb 2017
Yokohama, Japan

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HONG KONG OBSERVATORY

TC Rapid Intensification poses great threat to coastal livelihood and properties

Some examples in 2016:
Meranti, Haima, Nock-ten….

CNN Regions » Typhoon Nock-ten strands thousands in Philippines

Story highlights

NEW: Super Typhoon Nock-ten has forced the closure of ports, stranding thousands

NEW: The typhoon has weakened but is still equivalent to a Category 4 hur

(7 a.m. ET) on Christmas

Authorities rushed to eva
Philippines ahead of Noc

Manila, Philippines (CNN) — Super Typhoon Nock-ten has left more than 11,000 passengers stranded after roaring into the Philippines and forcing the closure of ports in the Southeast Asian country.

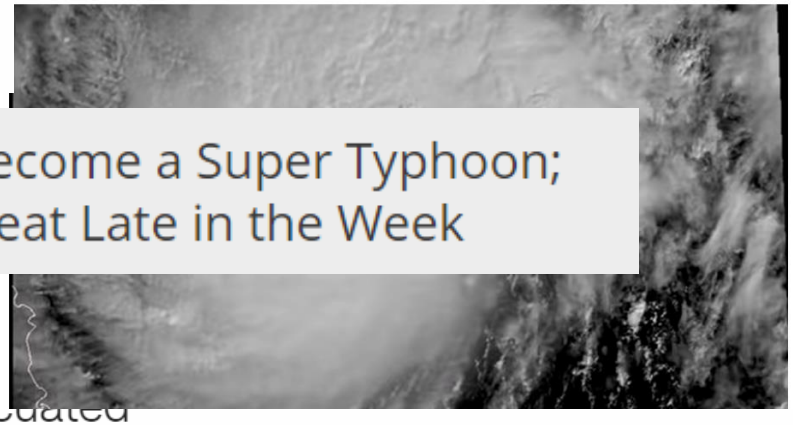
MashableAsia VIDEOS SOCIAL MEDIA TECH BUSINESS ENTERTAINMENT WORLD LIFESTYLE WATERCO

Super Typhoon Nock-ten rapidly intensifies, poses major Christmas threat to Philippines

.3k SHARES Share on Facebook Share on Twitter +

After a period of rapid intensification Monday and Tuesday, which saw Meranti grow from a Category 1 equivalent storm to that of a top-scale Category 5 in only 24 hours, the super typhoon has maintained winds of 190 mph (305 kph) for nearly 24 hours.

Typhoon Haima Rapidly Intensifies and May Become a Super Typhoon; Northern Philippines and Southeast China Threat Late in the Week



Thousands evacuated

The National Disaster Risk Reduction and Management Council (NDRRMC) said that as of 8 a.m local time on Monday, 77,560 families -- 383,097 people -- were in evacuation centers in Calabarzon, Mimaropa, Bicol and Easter Visayas.

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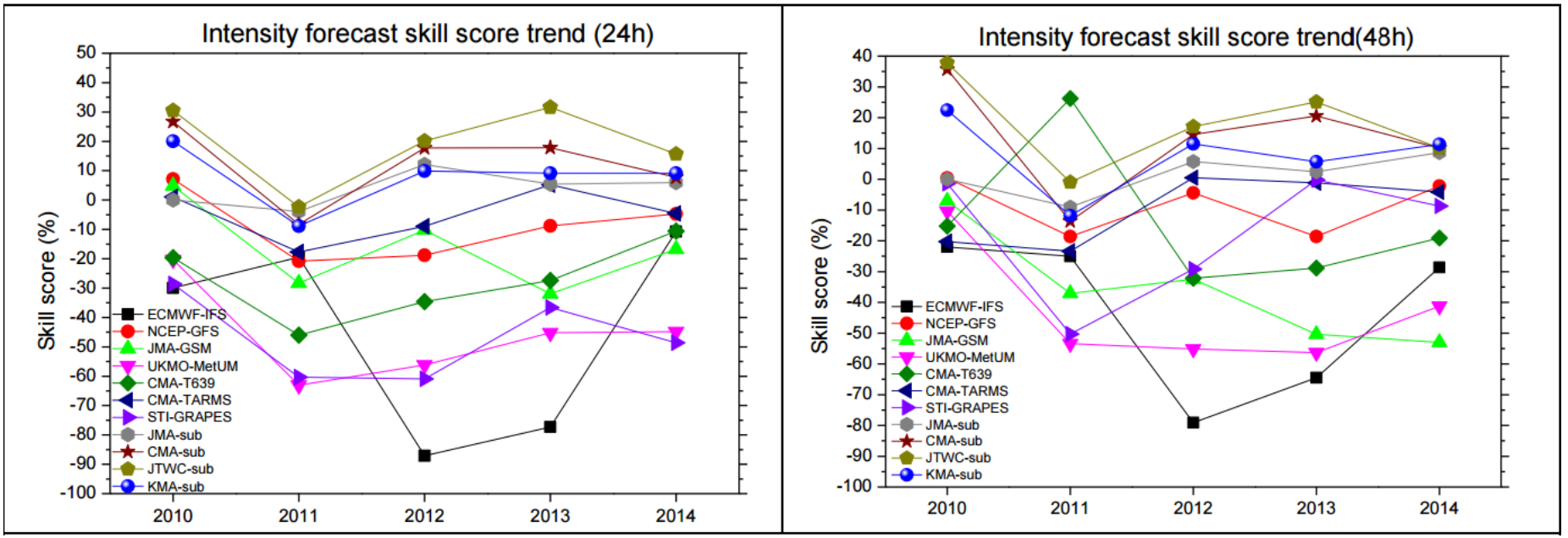
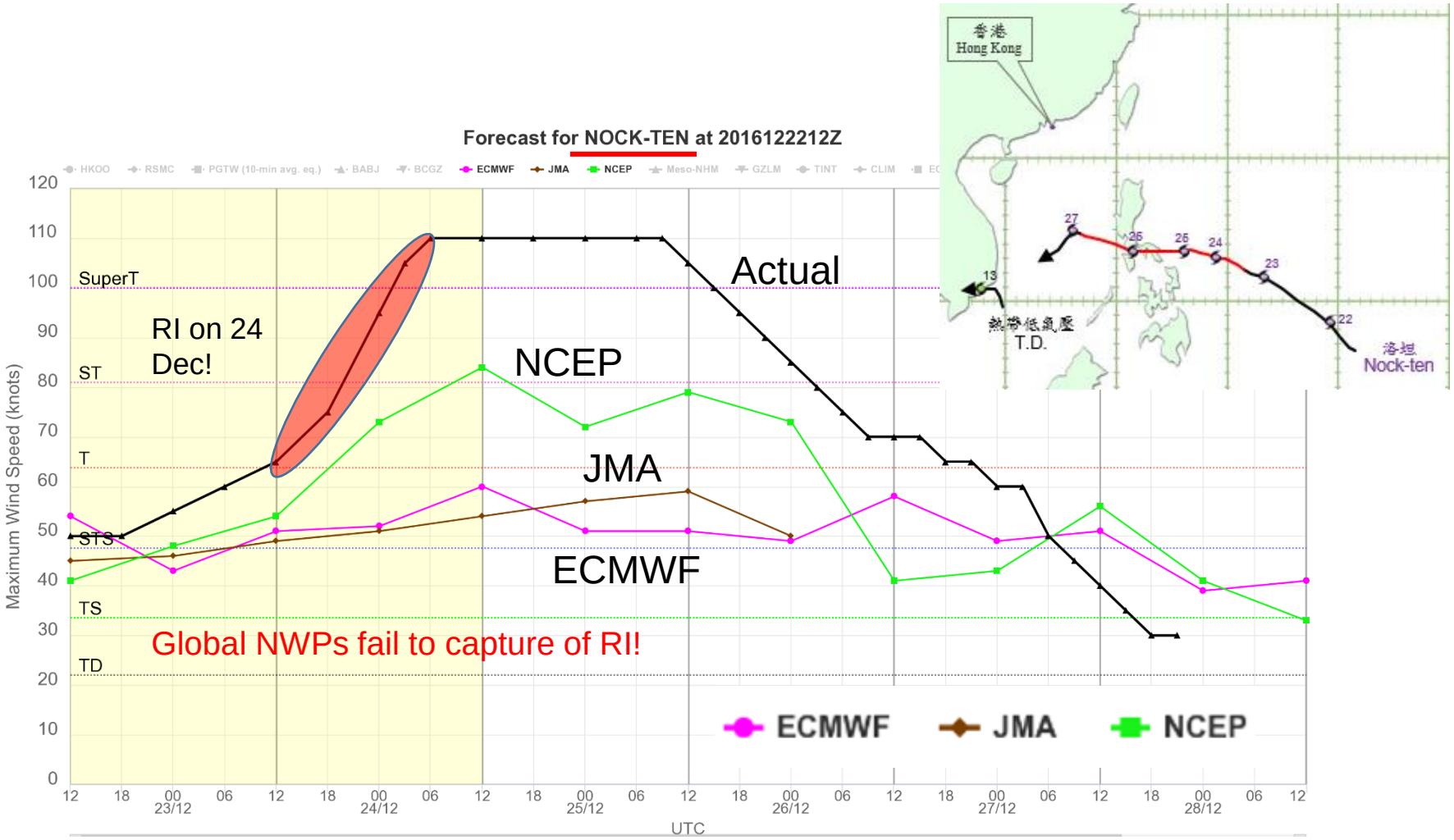
Intensity forecasting skill in WNP only showed limited improvement in recent years



TC Intensity forecast skill score trend (referring to RSMC-Tokyo best track dataset) at 24h (left) and 48h (right) for subjective methods, global models and regional models

(Reference : Progress of WMO Typhoon Landfall Forecast Demonstration Project (WMO-TLFDP), http://www.typhooncommittee.org/3rdJS/Docs/6.%20Cross-cutting/6.3%20Progress%20of%20WMO-TLFDP.pdf)

Rapid Intensification (RI) is a major challenge for global NWP models and operational TC forecasting

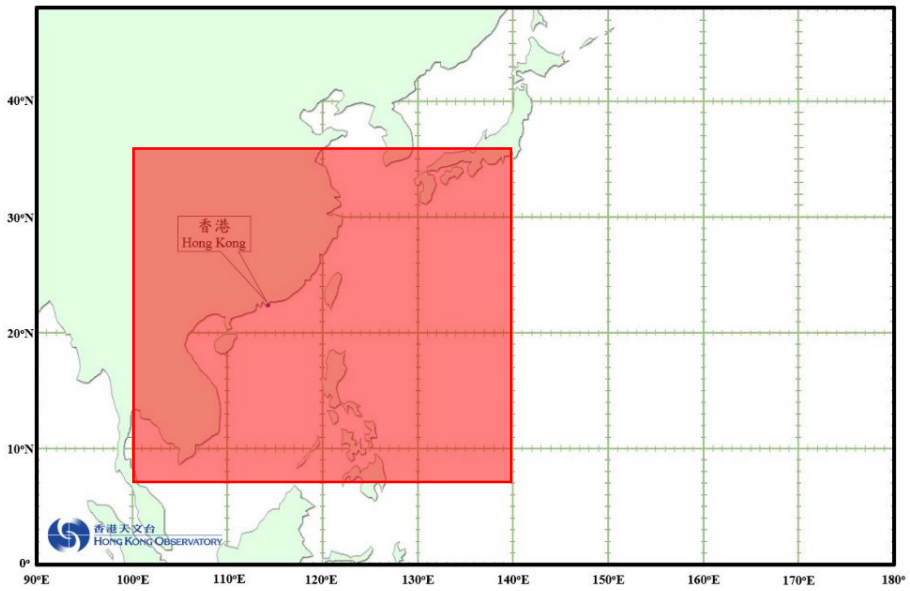


Objective

To develop a new statistical-dynamical forecasting tool (module) which works together with HKO's current TC intensity forecast model (TINT) to assess the probability of RI of tropical cyclones over the TC forecast area of HKO in the western North Pacific, up to 48 hours. This new module is named as **TINT-RI**.

HKO Forecast Area

- 7 – 36^{o} N, 100 – 140^{o} E



Data Set

- HKO Best track data (2009 – 2015)
- Atmospheric predictors from ECMWF ERA-Interim reanalysis data, with a spatial resolution of about 80 km
- Tropical Cyclone Heat Potential (TCHP) gridded 0.25^{o} from NOAA AOML Physical Oceanography Division

TINT – Tropical cyclone INTensity Guidance

- TINT is a statistical-dynamical TC intensity forecast model developed by the Hong Kong Observatory in 2014, which provides TC intensity forecast over the operational forecast area of HKO up to 72 hours

- TINT applies multiple linear regression to a list of predictors (e.g. TCHP, 850 hPa vorticity…etc) to provide intensity forecast

(Reference : C. Y. Y. Leung et al, Development of statistical Tropical Cyclone intensity forecast model, 29th Guangdong-Hong Kong-Macao Seminar on Meteorological Science and Technology, Macao, 20-22 Jan 2015 (http://www.hko.gov.hk/publica/reprint/r1171.pdf, Chinese version only))

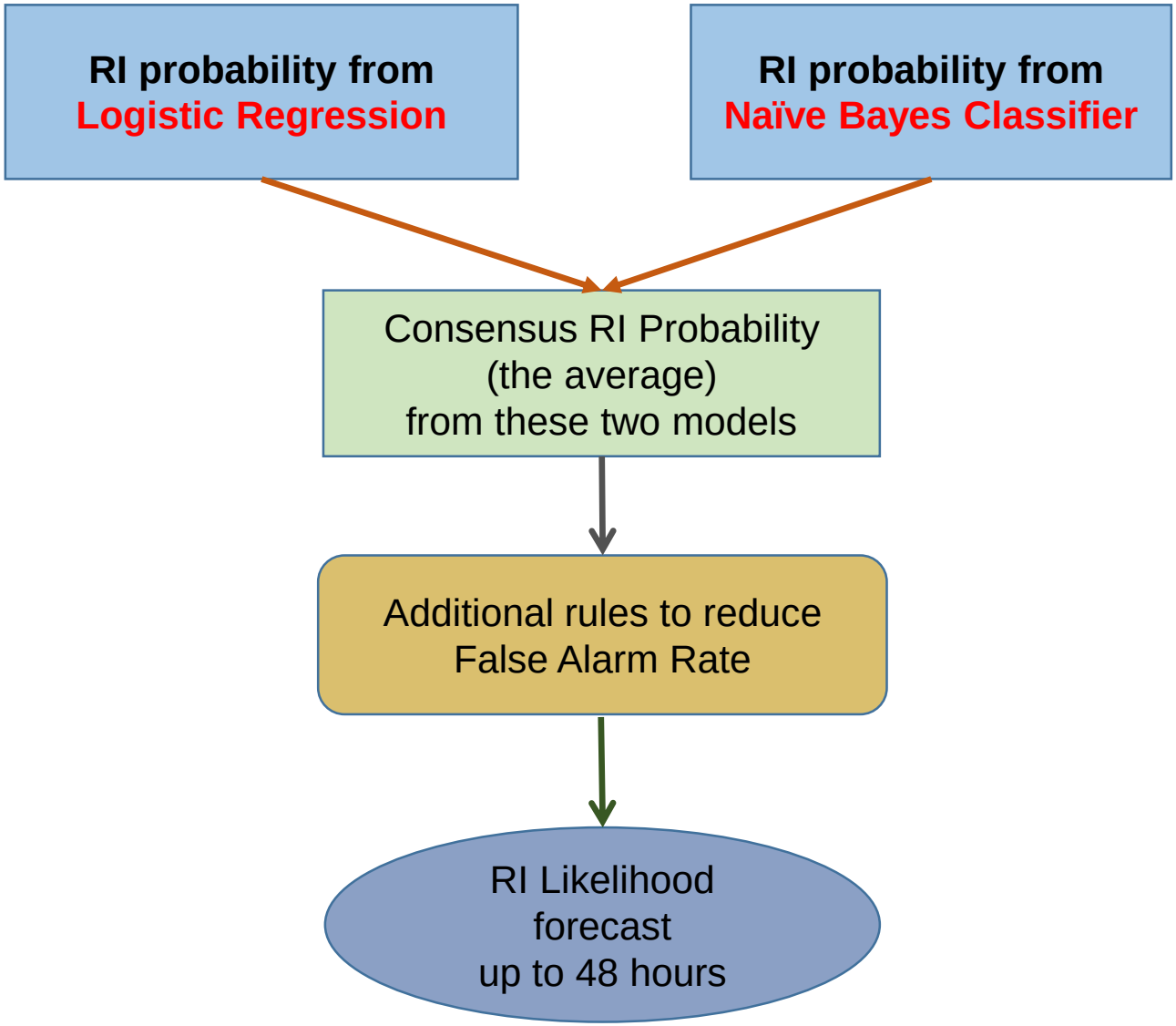
Defining TC Rapid Intensification

- Rapid Intensification (RI) is commonly defined by the 95th percentile of intensity change (e.g. Kaplan et al. 2010), e.g. RI over the Atlantic and ENP basins would be +30 kt / 24 hrs (1-min average)
- After converting to the WMO 10-min average, RI definition in the western North Pacific and the South China Sea adopt in the study will be :

Hours	WNP	Atlantic
12 hours	+ 15 kt	+ 20 kt
24 hours	+ 25 kt	+ 30 kt
36 hours	+ 40 kt	+ 45 kt
48 hours	+ 50 kt	+ 55 kt

(Reference : J. Kaplan, M. DeMaria, and J. A. Knaff, 2010: A Revised Tropical Cyclone Rapid Intensification Index for the Atlantic and Eastern North Pacific Basins. *Wea. Forecasting*, **25**, 220-241.)

Framework of TINT-RI

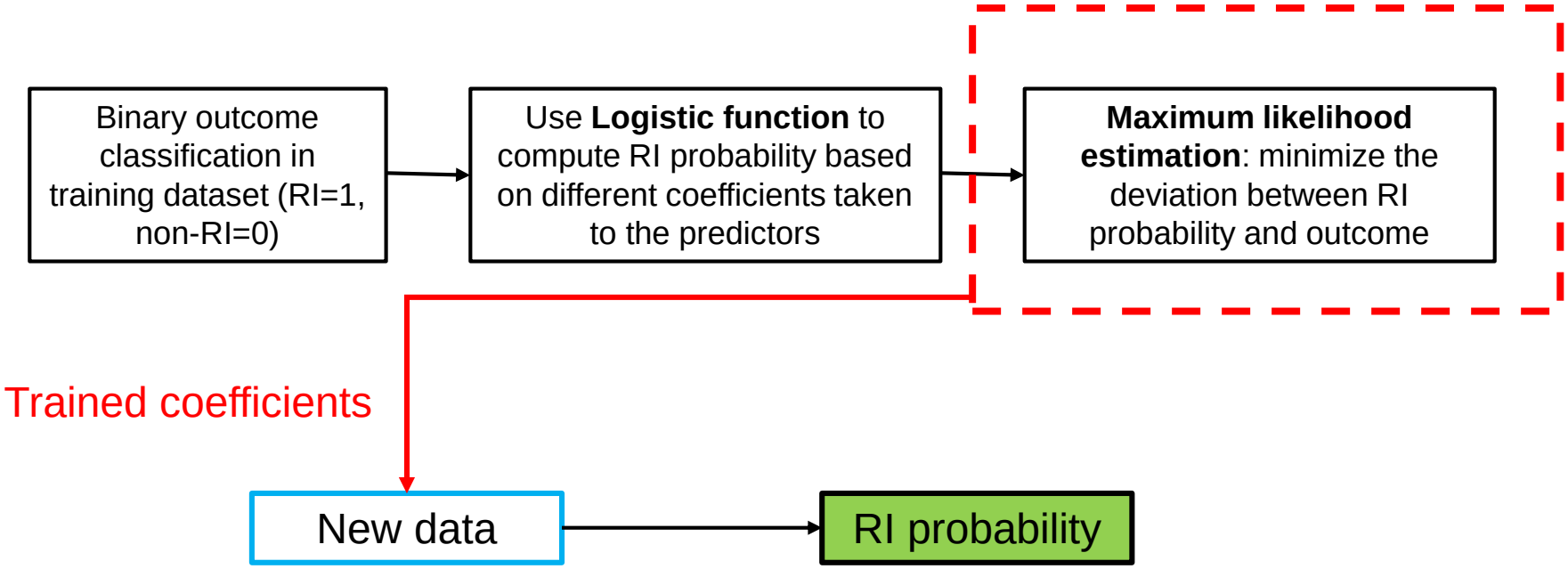


Identified predictors

- Incorporate atmospheric, oceanic factors and TC characteristics
- Performance optimized
- Correlation between predictors minimized

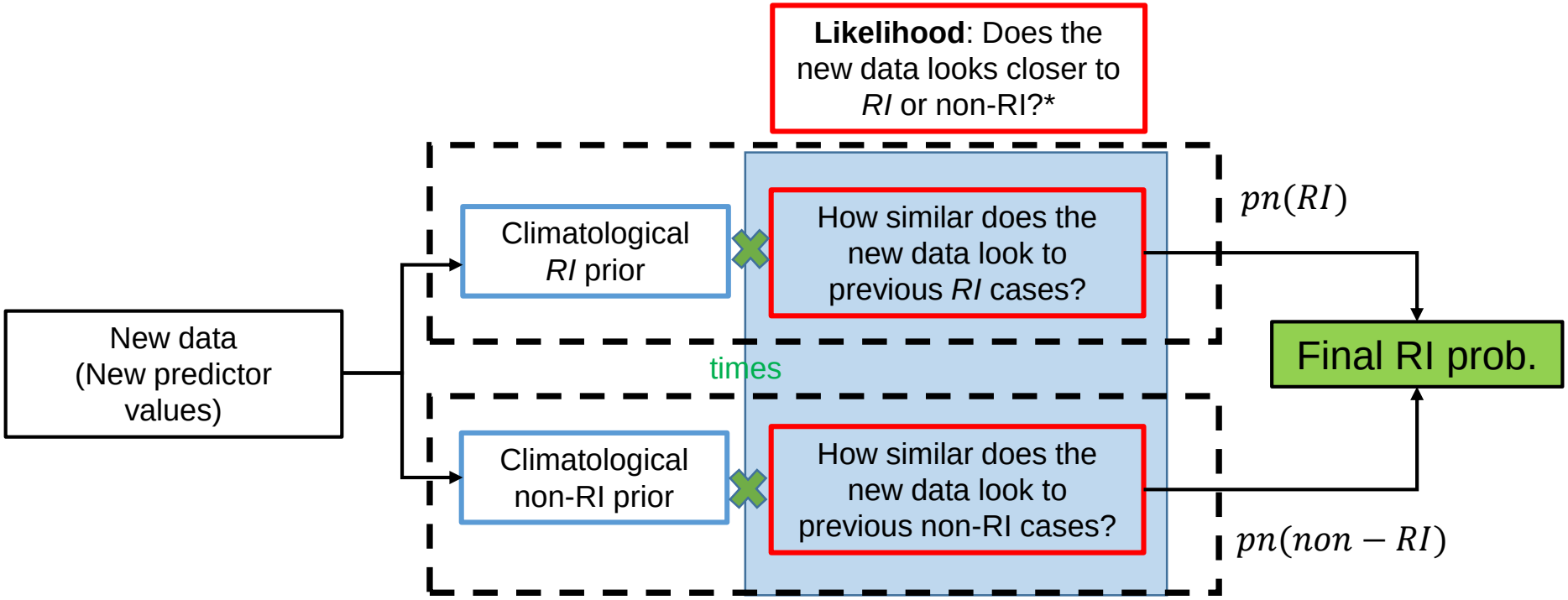
Category	Predictors (Total: 6 predictors)
Ocean	Tropical Cyclone Heat Potential (TCHP) nearest to the TC
Atmosphere (from ECMWF ERA-Interim reanalysis)	200hPa divergence averaged over 9^{o} radius 300-500hPa RH averaged from 2^{o} to 7^{o} radius 200-850hPa Space Mean Vertical Wind Shear (VWS) averaged over 5^{o} radius
TC characteristics	Persistence (previous 12-hour intensity change) Current Intensity (Actual analysis)

Logistic Regression



Naïve Bayes Classifier

The heart of Naïve Bayes Classification: It takes BOTH sides(RI and non-RI) into account AT THE SAME TIME

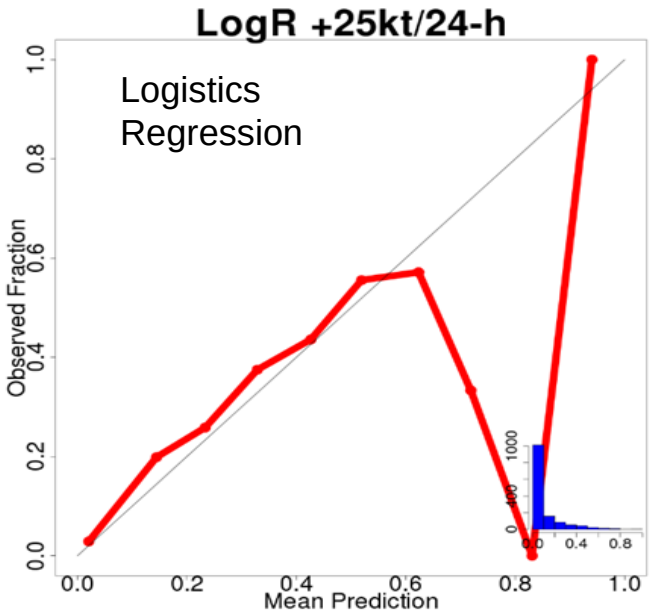


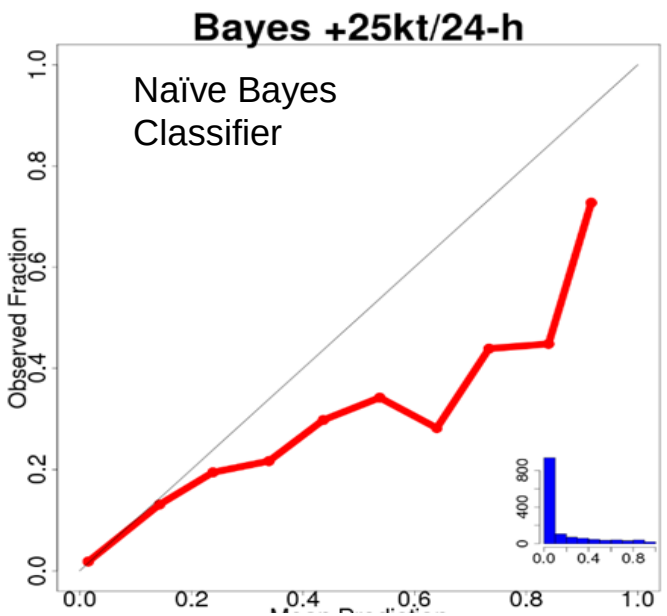
$$RI\ probability = \ posterior = \frac{pn(RI)}{evidence} = \frac{pn(RI)}{pn(RI)+pn(non-RI)}$$

*Assume previous predictors follow Normal Distribution

Logistics Regression vs Naïve Bayes Classifier

Reliability diagrams of two models based on training data, with diagonal line being the perfect forecast





Logistics Regression provide reliable forecast at lower probability but performs poorly when probability is high

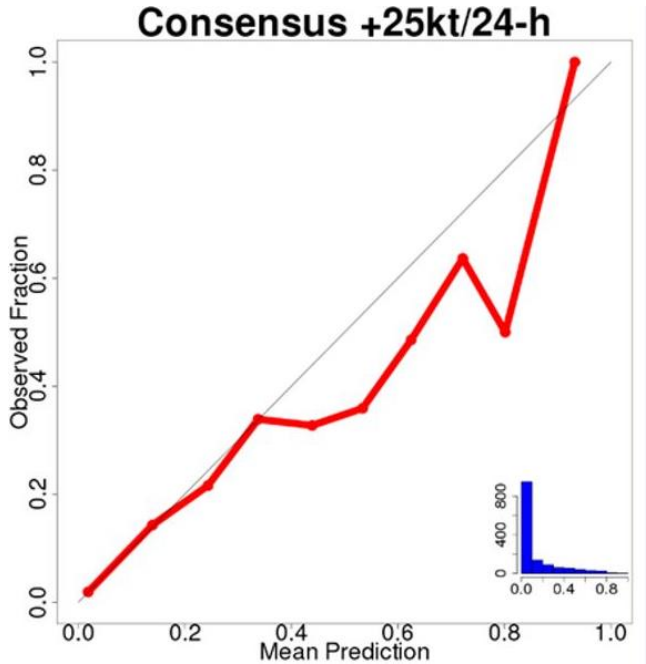
Naïve Bayes Classifier provides less reliable forecast compared with logistic regression at lower probability, but it is more reliable model for higher probabilities.

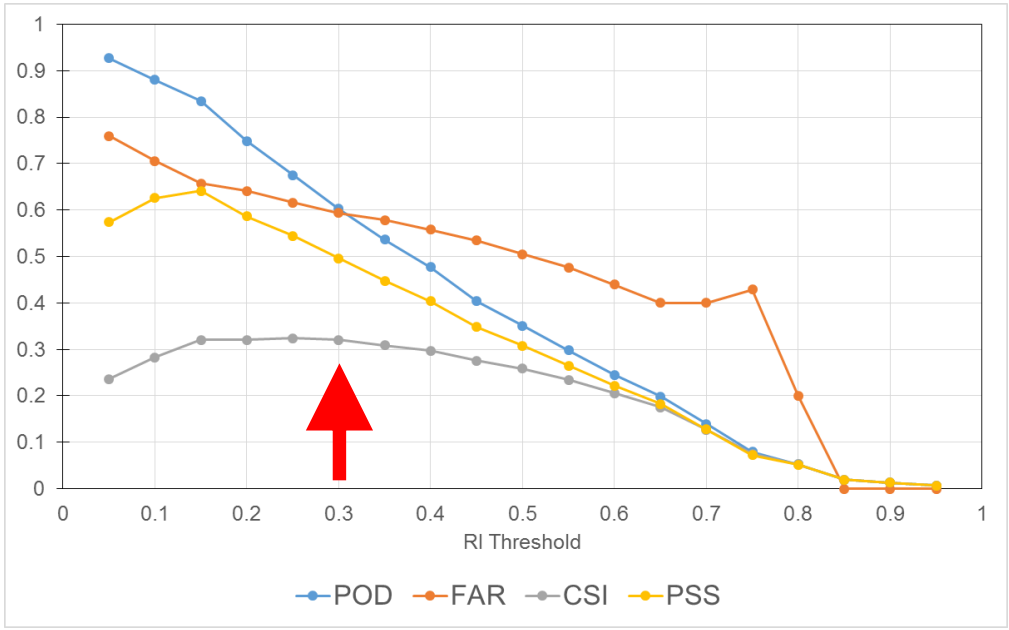
Consensus RI probability

- To optimize the performance, consider consensus RI probability (P_{con})

  $P_{con} = ½(P_{LogR} + P_{Bayes})$

- RI Threshold chosen as 0.3 where the CSI is about maximum





Training data from 2009 to 2015

Additional rules to lower FAR

As the false alarm rate (FAR) of the consensus probability is still rather high, the following two additional rules are identified and adopted to further reduce the FAR

(1) TINT intensity gain rule

(2) Change of Vertical Wind Shear (VWS) rule

Rule 1 - TINT intensity gain rule

- Made reference to the intensity forecast from the statistical-dynamical TC intensity forecast model (TINT)

- If TINT only suggests slight intensity gain (below pre-defined thresholds), **RI forecast is forced to Negative irrespective of RI probability**

- Thresholds of intensity change (with respect to initial intensity) :

  ≤+5kt/12-h, ≤+10kt/24-h, ≤+15kt/36-h, ≤+20kt/48-h

Example of TINT Intensity Gain Rule -

+10kt/24-h threshold is not met, but RI Forecast is Positive → RI forecast is set to negative although RI probability is high

	+12-h	+24-h	+36-h	+48-h
Actual Intensity change w.r.t. initial (knot)	+5	+5	+0	+0
TINT forecast intensity change w.r.t. initial (knot)	+9	+6	-13	-19
RI probability	83.9% (False Alarm)	73.8% (False Alarm reduced to correct negative)	9.3% (Correct negative)	4.1% (Correct negative)

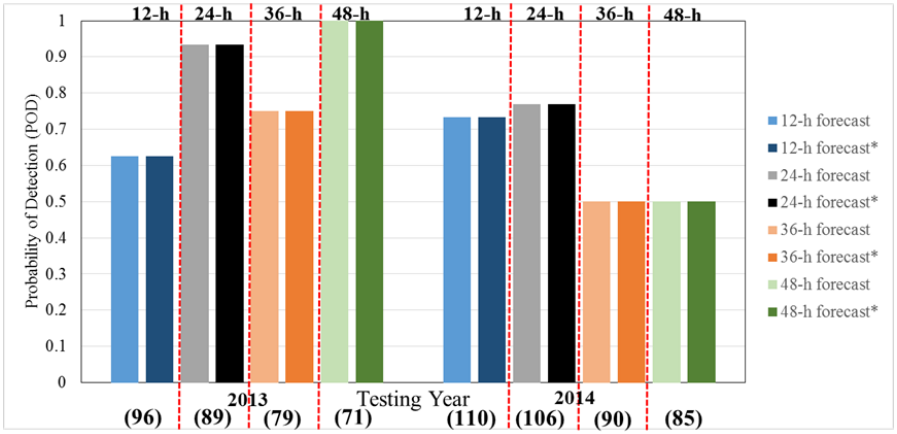
Rule 2 - Change of Vertical Wind Shear (VWS) Rule

- Made reference to previous 12-h change of model Vertical Wind Shear (VWS)
- If VWS increased too much → Not favorable to RI
- VMS thresholds extracted from RI range in training dataset
- RI is forced to Negative if VMS change exceeded the corresponding predefined threshold

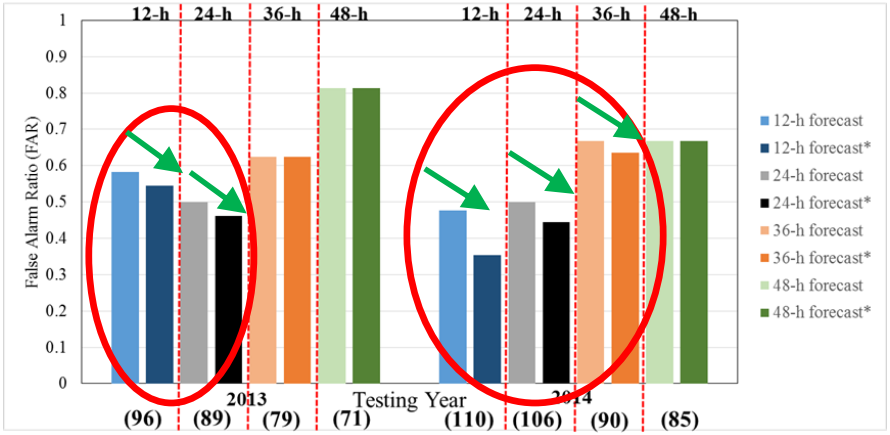
VMS Threshold	+12-h	+24-h	+36-h	+48-h
(m/s)	≥+4.2	≥+4.0	≥+3.9	≥+3.9

Improvement in performance with additional rules

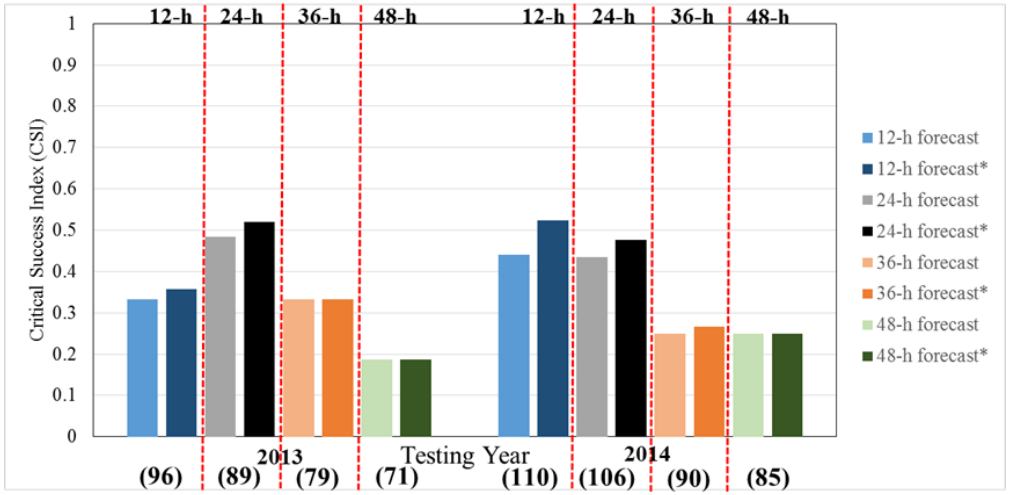
No change in POD



Reduced FAR



Improved CSI



* represents performance after implementing the two rules

Performance in different probability intervals

Prob. Range	False Alarm Ratio
30% - 40%	0.58
40% - 50%	0.74
50% - 60%	0.53
60% - 70%	0.57
70% - 80%	0.44
80% - 90%	0.25
90% - 100%	0

Likely group

Very likely group

RI Forecast is Positive

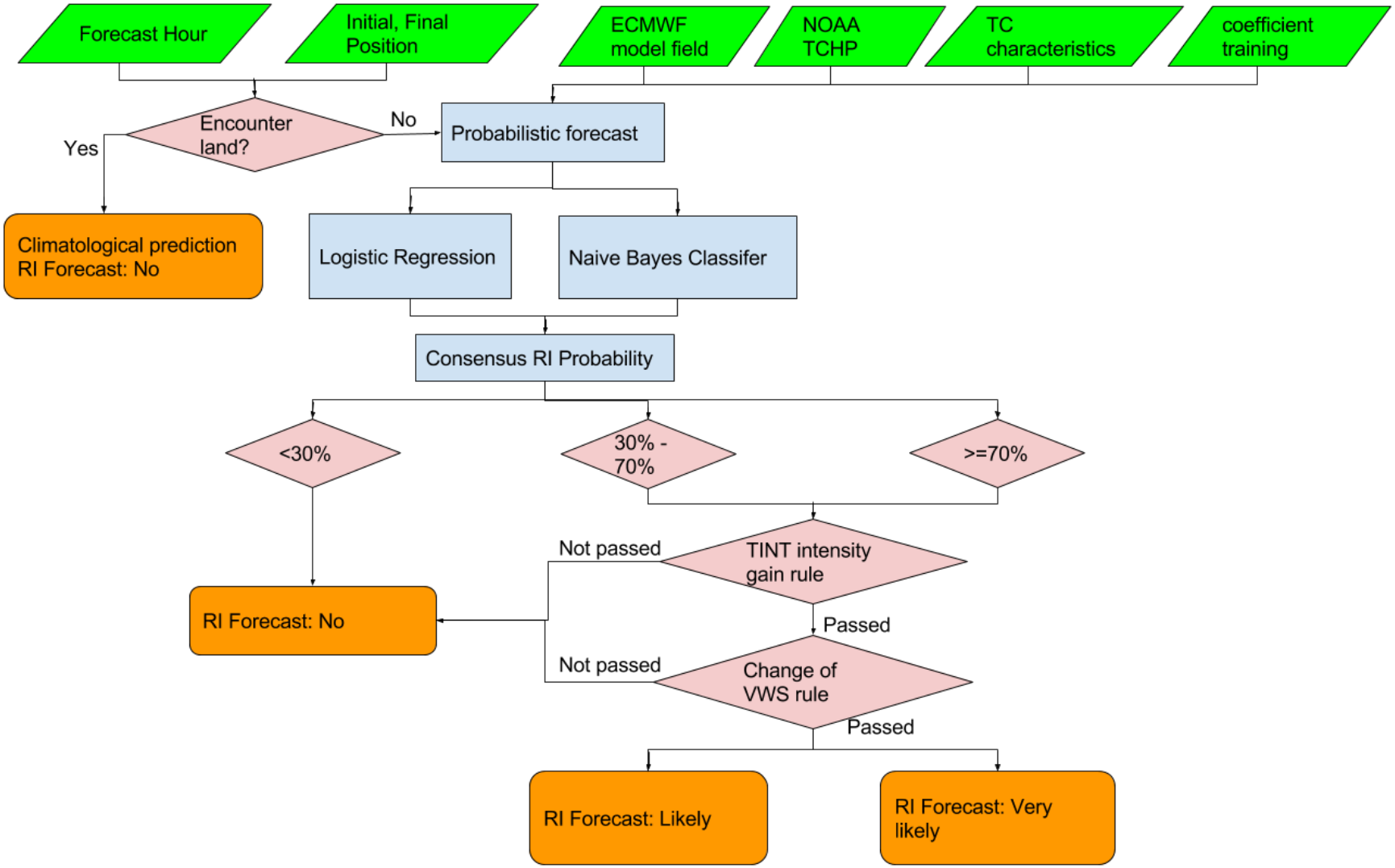
Decreasing FAR

FAR is reduced for higher RI probability --> More confidence of RI forecast!

Divide RI (prob.≥30%) into two classes for forecasters' reference:

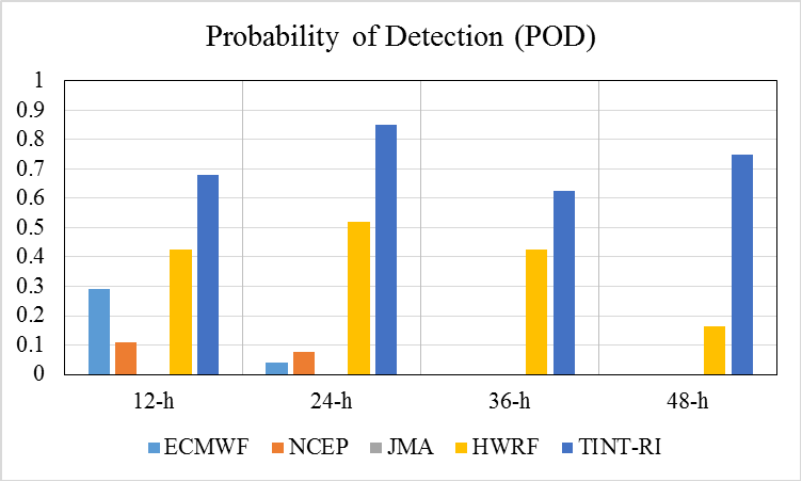
- **Very likely** (for prob. ≥ 70%)
- **Likely** (for 30% ≤ prob.<70%)

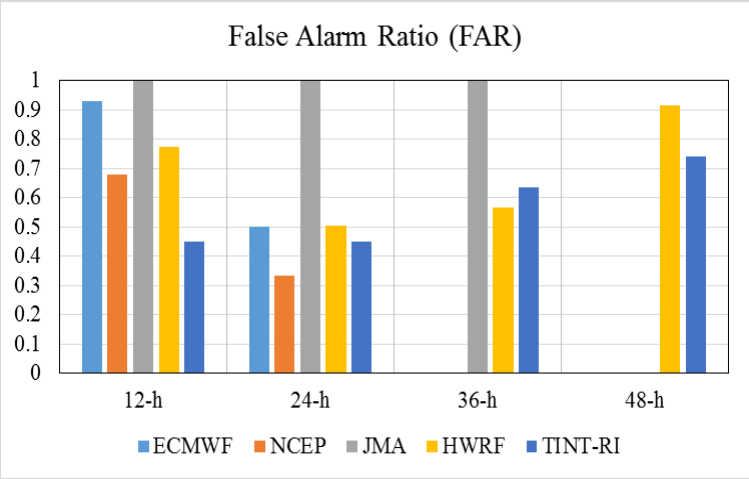
Overall Flow Chart of TINT-RI Operation

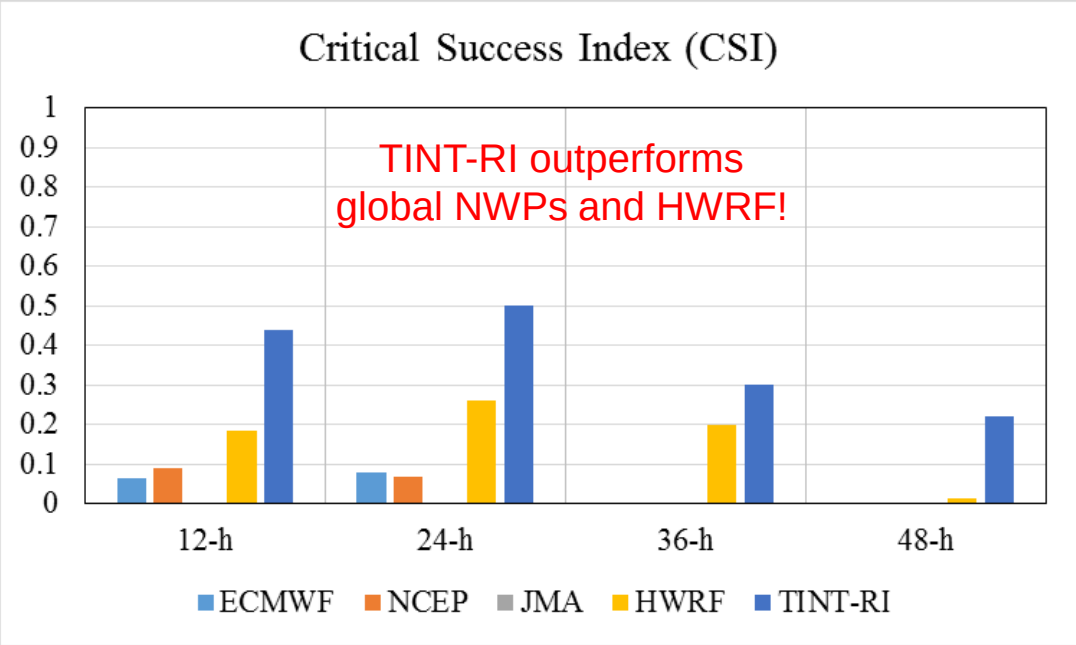


Cross validation verification of 2013 and 2014

Apart HWRF, other three NWPs have low skill in RI prediction





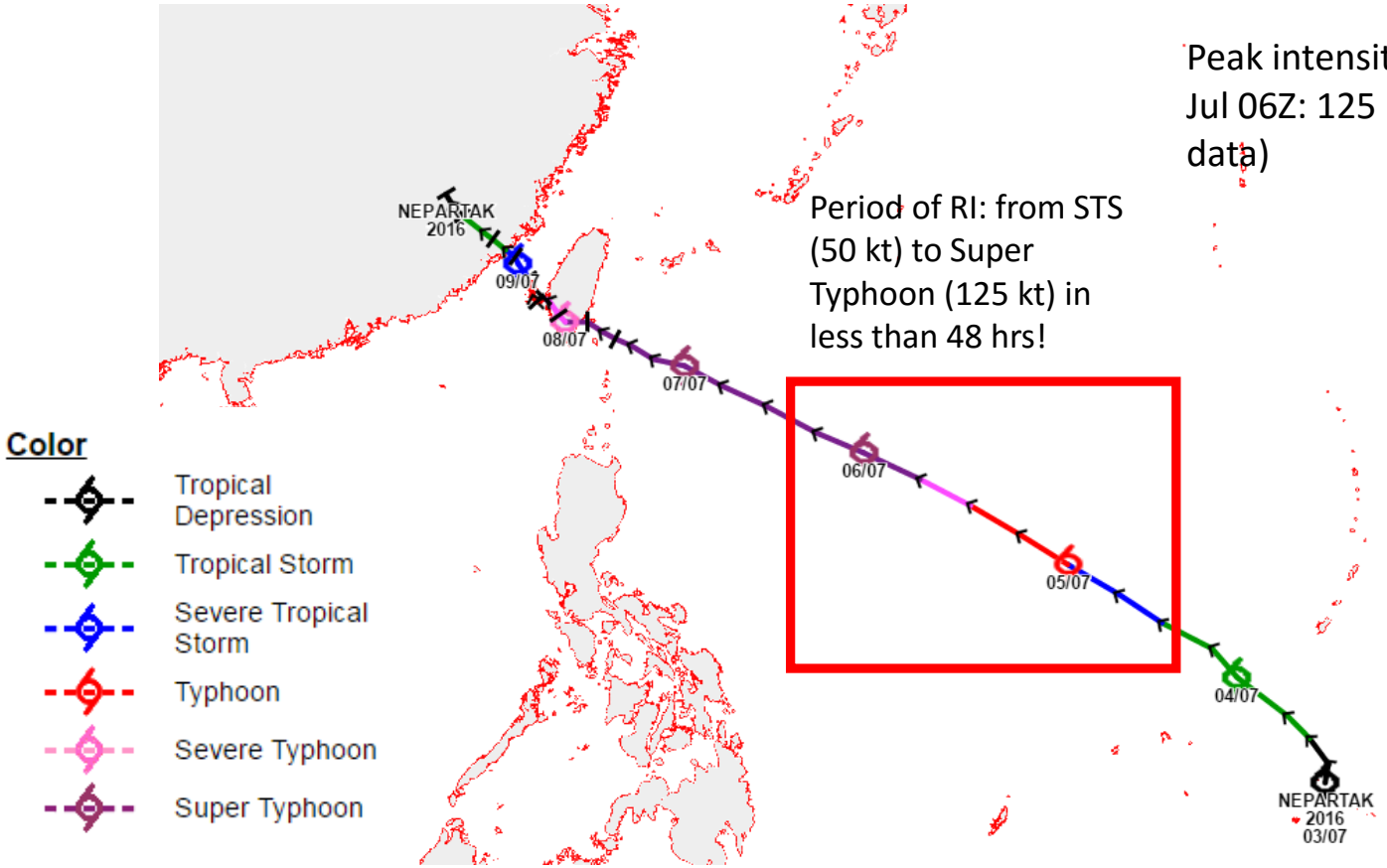


CSI of TINT-RI ranged from 0.22 to 0.5

For global NWPs and HWRF:

- Forecasts from DMOs are converted into a binary RI forecast (i.e. RI forecast is positive if the forecasted intensity change exceeded the corresponding RI definition)

Case Study: Super Typhoon Nepartak (1601)

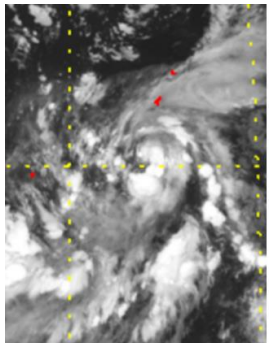


Peak intensity of Nepartak at 6 Jul 06Z: 125 kt (HKO best track data)

Period of RI: from STS (50 kt) to Super Typhoon (125 kt) in less than 48 hrs!

Pick 3 forecast time (3 Jul 12Z, 4 Jul 12Z and 5 Jul 12Z) to evaluate the performance

Forecast for Nepartak at 3/7/2016 12Z
T+0: 35 kt (TS)

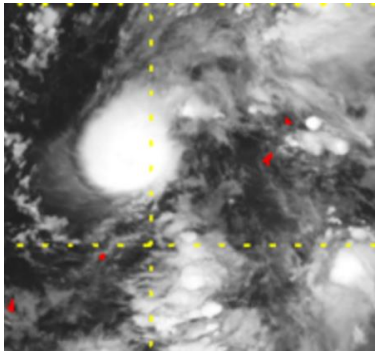


Model	+12-h	+24-h	+36-h	+48-h
ECMWF	+6	+17	+16	+19
NCEP	+17	+22	+21	+35
JMA	+9	+20	+25	+43
HWRF	+33	+38	+33	+48
TINT	+13	+25	+36	+44
TINT-RI	Likely(≥+15)	Very Likely(≥+30)	Very Likely(≥+40)	Very Likely(≥+50)
Actual	+5	+15	+35	+60

False
Hit
Miss

Early false alarm for TINT-RI, but able to hit RI in T+48 hrs

Forecast for Nepartak at 4/7/2016 12Z
T+0: 50 kt (STS)

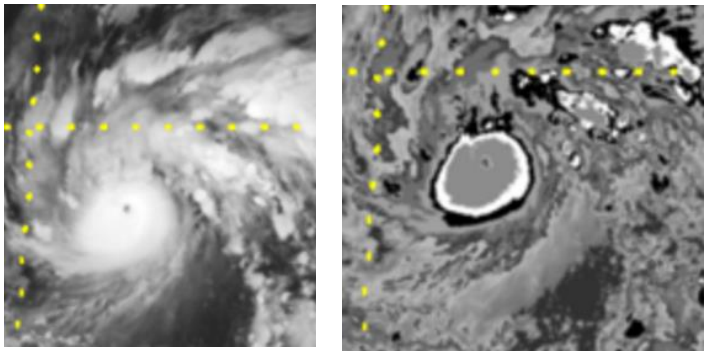


Model	+12-h	+24-h	+36-h	+48-h
ECMWF	-2	+6	+25	+17
NCEP	+4	-5	-3	+11
JMA	-8	+7	+13	+24
HWRF	+21	+14	+20	+44
TINT	+10	+20	+30	+40
TINT-RI	Likely(≥+15)	Very Likely(≥+30)	Likely(≥+40)	Likely(≥+50)
Actual	+20	+45	+70	+75

False
Hit
Miss

TINT-RI gives correct positive for all time range while DMOs from major global NWPs cannot capture the initiation of RI!

Forecast for Nepartak at 5/7/2016 12Z
T+0: 85 kt (ST)



Model	+12-h	+24-h	+36-h	+48-h
ECMWF	+2	+12	+8	+24
NCEP	-17	-16	+0	-8
JMA	+16	+27	+38	+40
HWRF	+30	+14	+26	+23
TINT	+12	+17	+13	+9
TINT-RI	Very Likely(≥+15)	Likely(≥+30)	No	No
Actual	+25	+30	+30	+25

False
Hit
Miss

This forecast is “Likely” originally, but changed to “No” due to TINT forecast is ≤+15 kt/36-h (TINT intensity gain rule).

Operational Display

TINT-RI forecast usually available approximately T+8 hours from the base time!

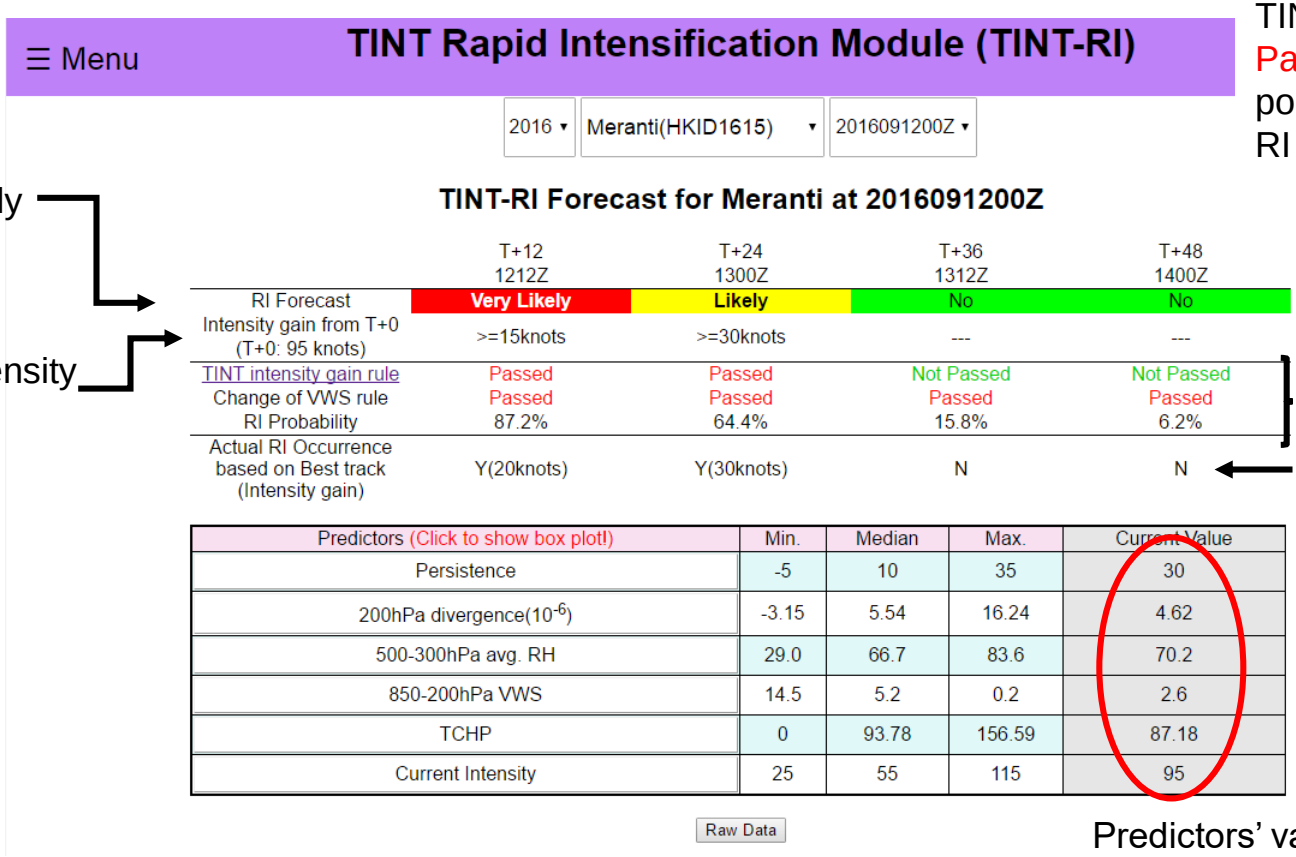
RI Forecast
Red: Very Likely
Yellow: Likely
Green: No

Suggested intensity gain from T+0

Forecast reasoning
TINT rule & VWS rule: Passed (RI is possible) /Not Passed
RI Probability

Actual RI Occurrence for forecasters' reference

Predictors' values



Preliminary verification of the TINT-RI performance in 2016 (based on HKO provisional best track dataset)

CSI of 2016 range from around 0.34 to 0.48 comparable to the testing year in 2013 and 2014!

	+12-h	+24-h	+36-h	+48-h
No. of forecast	146	129	115	107
Hit	15	19	10	11
Miss	9	4	5	4
False Alarm	17	19	14	8
Correct Negative	94	71	69	59
POD	0.63	0.83	0.67	0.73
FAR	0.53	0.5	0.58	0.42
CSI	0.37	0.45	0.34	0.48

Future Work and Challenges

- Very low RI probability in South China Sea comparing with the western North Pacific, leading to relatively low skill of TINT-RI in the South China Sea.

- Further study to refine the algorithm with a view to improving the skills of prediction, in particular over the South China Sea (e.g. by incorporating predictors from satellite observations and other NWP model products as well as identifying a new set of RI definitions in South China Sea based on the climate characteristics in the region).

Thank you!

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HONG KONG OBSERVATORY

Logistic Regression

- Coefficients of the logit (L) fitted by maximum likelihood estimation

$$L = \beta_0 + \beta_1 x_1 + \ldots + \beta_6 x_6$$

- RI probability is computed by

$$P = \frac{1}{1 + e^{-L}}$$

Naïve Bayes Classifier

- Naïve: assume different predictors are not correlated
- Bayes: make use of Bayes theorem: $P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$
- All predictors are assumed to follow Normal distribution
- Likelihood of RI [*pn*(*RI*)] = *P*(*RI*) x probability mass function of predictors using RI mean and SD
- Likelihood of non-RI [*pn*(*non-RI*)] = *P*(*non-RI*) x probability mass function of predictors using non-RI mean and SD

The Naïve Bayes "RI Probability"

$$RI\ probability = \ posterior = \frac{pn(RI)}{evidence} = \frac{pn(RI)}{pn(RI)+pn(non-RI)}$$

- It follows that RI probability would be very high when
- (i) ***pn(non-RI)*** → 0 (when the data completely does not look similar to non-RI)
- (ii) ***pn(RI)*** » ***pn(non-RI)*** (the data may look a bit close to non-RI, but it looks a lot similar to RI than non-RI)