Storm Warning in Pre-Convection Environment from the New Generation of Geostationary Weather Satellite Advanced Imager Measurements

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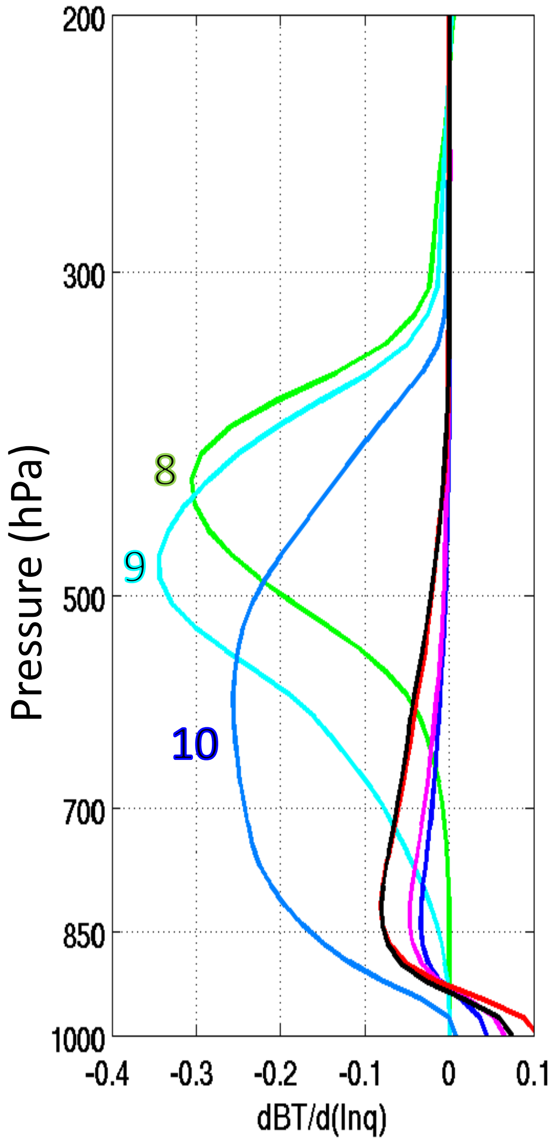
Outline

- 1. Overview on the applications of geostationary imager observations for nowcasting;
- 2. Using geostationary satellite imager data for local severe storm (LSS) nowcasting；
- 3. Machine learning based statistical prediction model for LSS warning in pre-convection;
- 4. Application examples;
- 5. Summary and future work.

The central wavelength and spatial resolution of AHI/ABI/AGRI bands

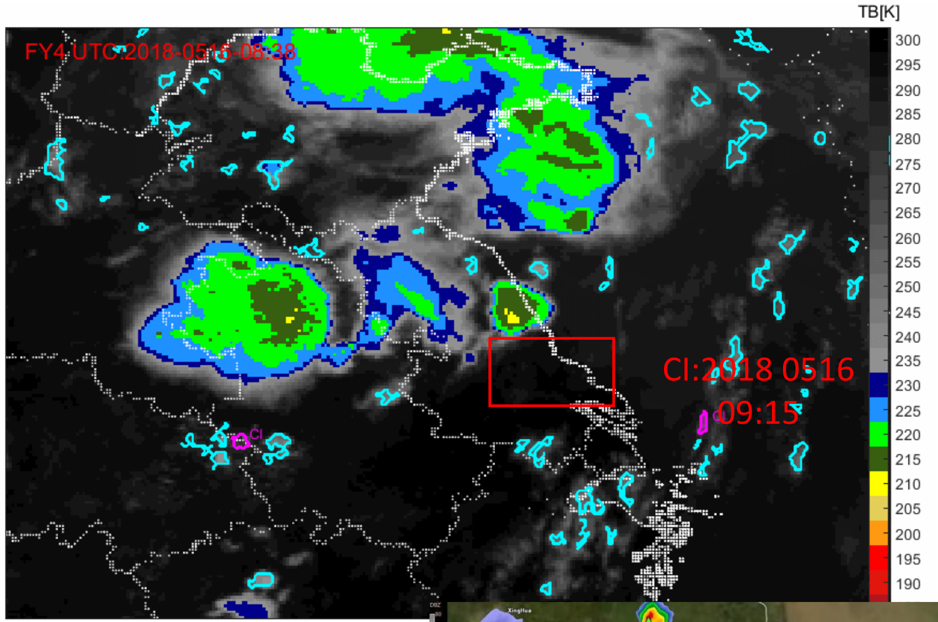
Himawari-8/AHI			GOES/ABI			FY-4A/AGRI		
Band	Central wavelength (μm)	Spatial Resolution (km)	Band	Central wavelength (μm)	Spatial Resolution (km)	Band	Central wavelength (μm)	Spatial Resolution (km)
1	0.46	1	1	0.47	1	1	0.46	1
2	0.51	1	2	0.64	0.5	2	0.64	0.5~1
3	0.64	0.5	3	0.86	1	3	0.86	1
4	0.86	1	4	1.37	2	4	1.38	2
5	1.60	2	5	1.6	1	5	1.61	2
6	2.30	2	6	2.2	2	6	2.25	2~4
7	3.90	2	7	3.9	2	7	3.80 (high)	2
8	6.20	2	8	6.29	2	8	3.80 (low)	4
9	7.0	2	9	6.9	2	9	6.5	4
10	7.3	2	10	7.3	2	10	7.2	4
11	8.6	2	11	8.4	2	11	8.5	4
12	9.6	2	12	9.6	2			
13	10.4	2	13	10.3	2			
14	11.2	2	14	11.2	2	12	11.0	4
15	12.3	2	15	12.3	2	13	12.0	4
16	13.3	2	16	13.3	2	14	13.3	4

AHI water vapor mixing ratio Jacobians using CRTM with standard atmosphere.

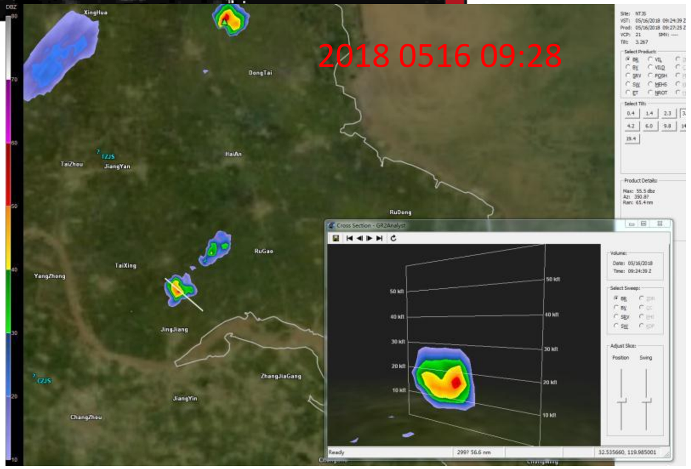


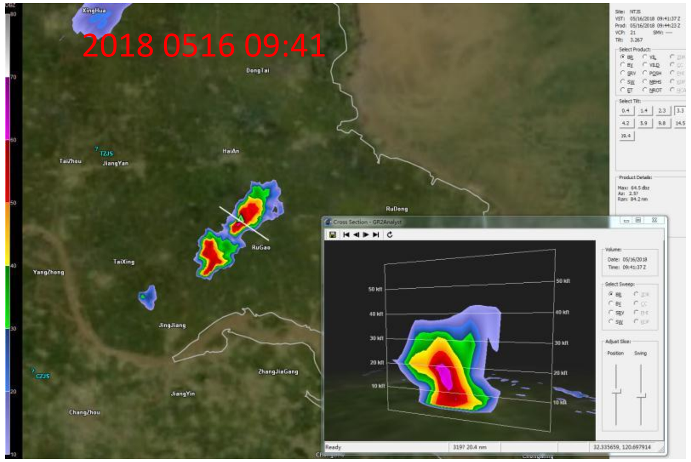
1. Overview on the applications of geostationary imager measurements for nowcasting

- Nowcasting related object detection
  - Convective Initiation;
  - Features and properties of storm top;
  - Mesoscale Convective System;
  - Storm classification (hail, deep convection etc.)
- Situation awareness using real-time or near real-time nowcasting products
  - Total precipitable water, layered precipitable water (LPW), instability indices;
- Image extrapolation using sequential images at different times
- Statistical prediction model for warning (in pre-convection, developing stage etc.)
- Assimilation of high resolution GEO data in storm scale NWP for Warn-on-Forecast (WoF) application (to be studied)



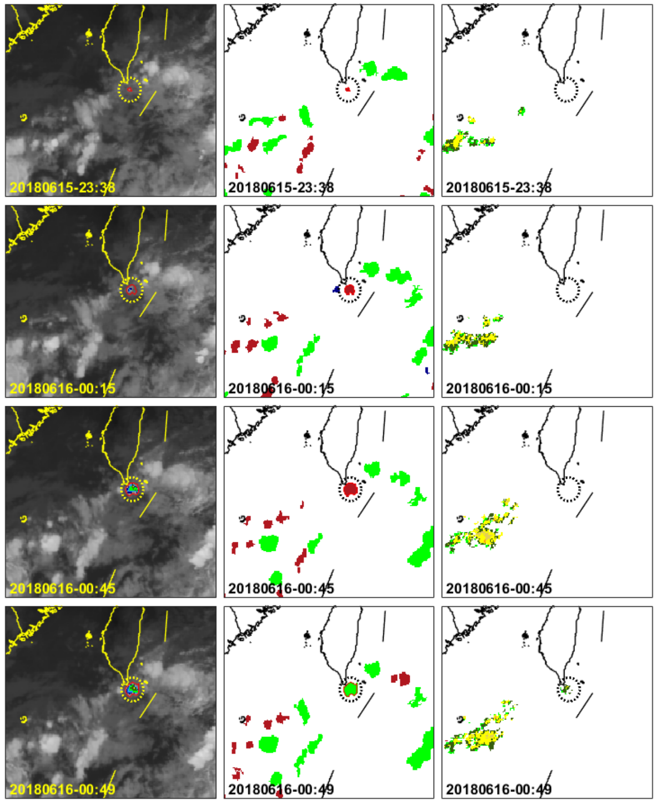
May 16, 2018, local severe storm (hail) occurred in Rudong County in Jiangsu Province.

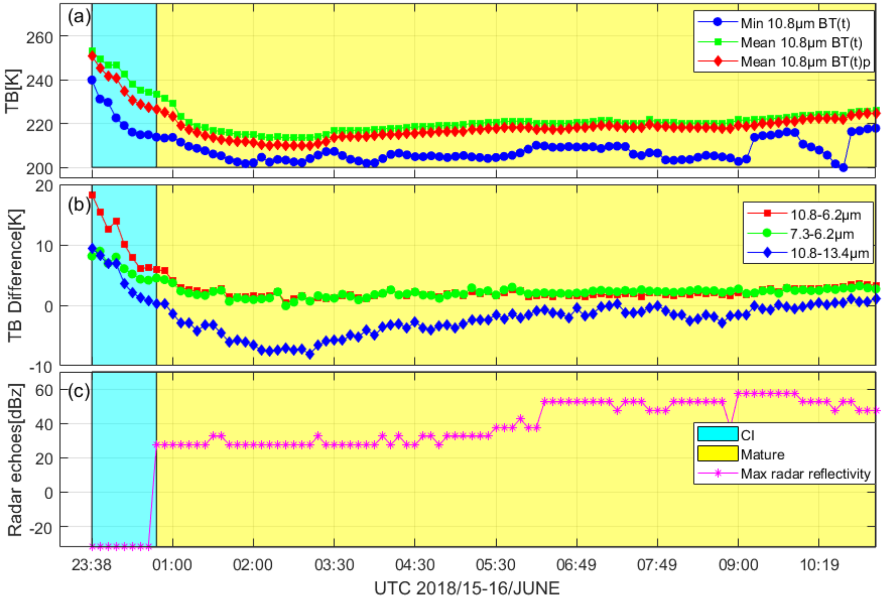




Fenglin SUN, NSMC

Over the sea south of Taiwan, a single defined cloud object of interest (with red boundaries) from (left) FY-4 4-km 10.8 μm channel imagery, (center) RDCMS nowcast output, and (right) radar reflectivity (dBZ), for the times listed on June 16, 2018. Note that RDCMS objects pertain to CI occurrences 1 hour and 11 minutes earlier than the radar data in this example.





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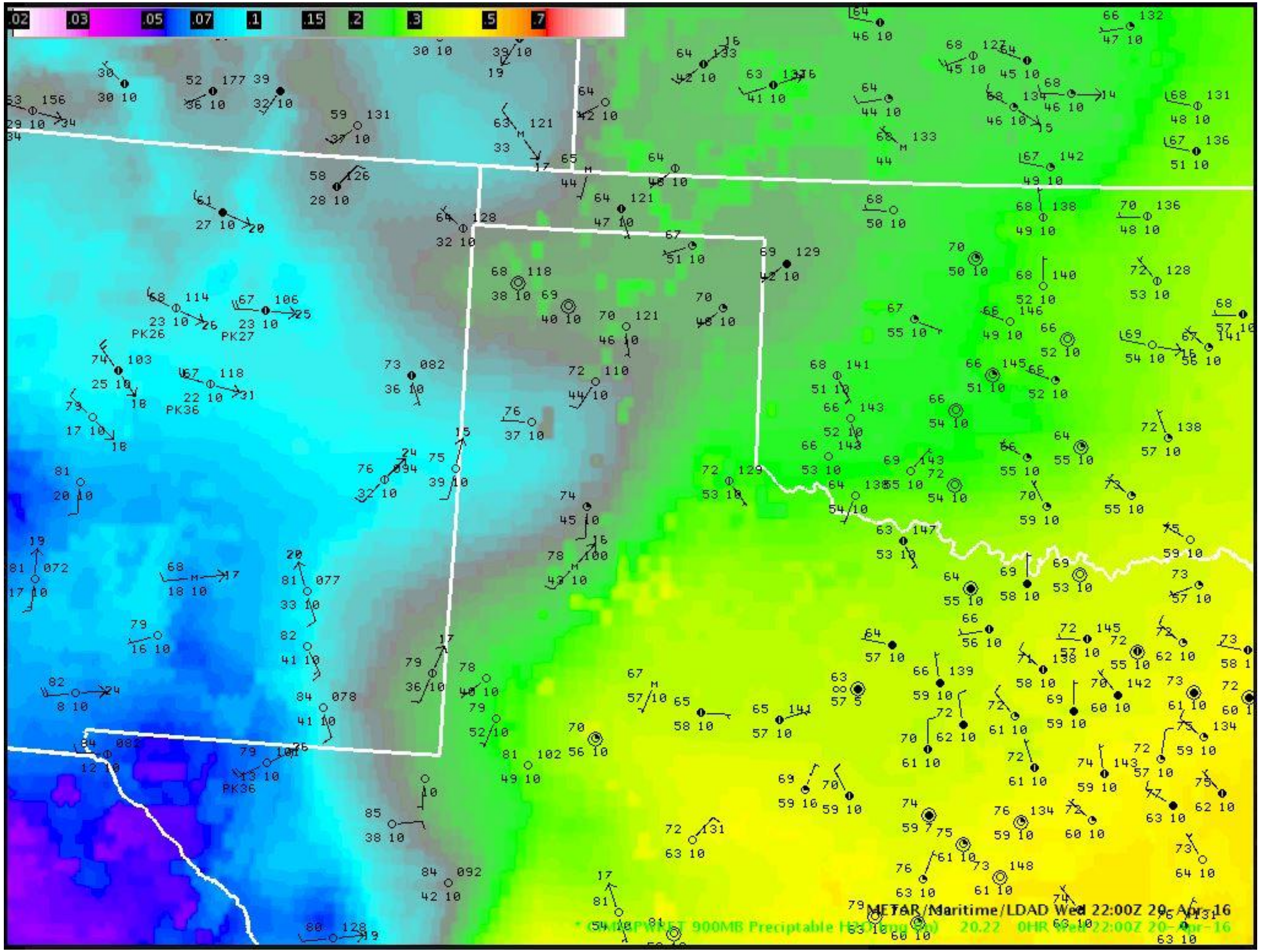
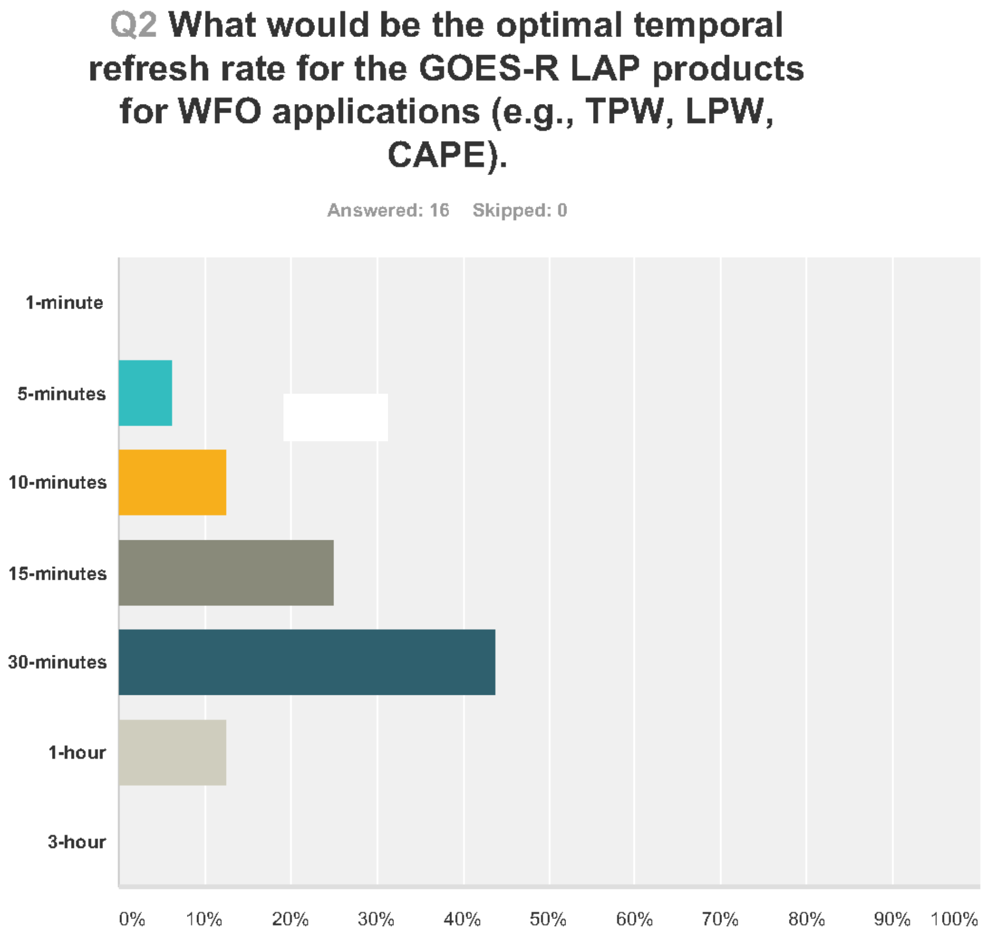
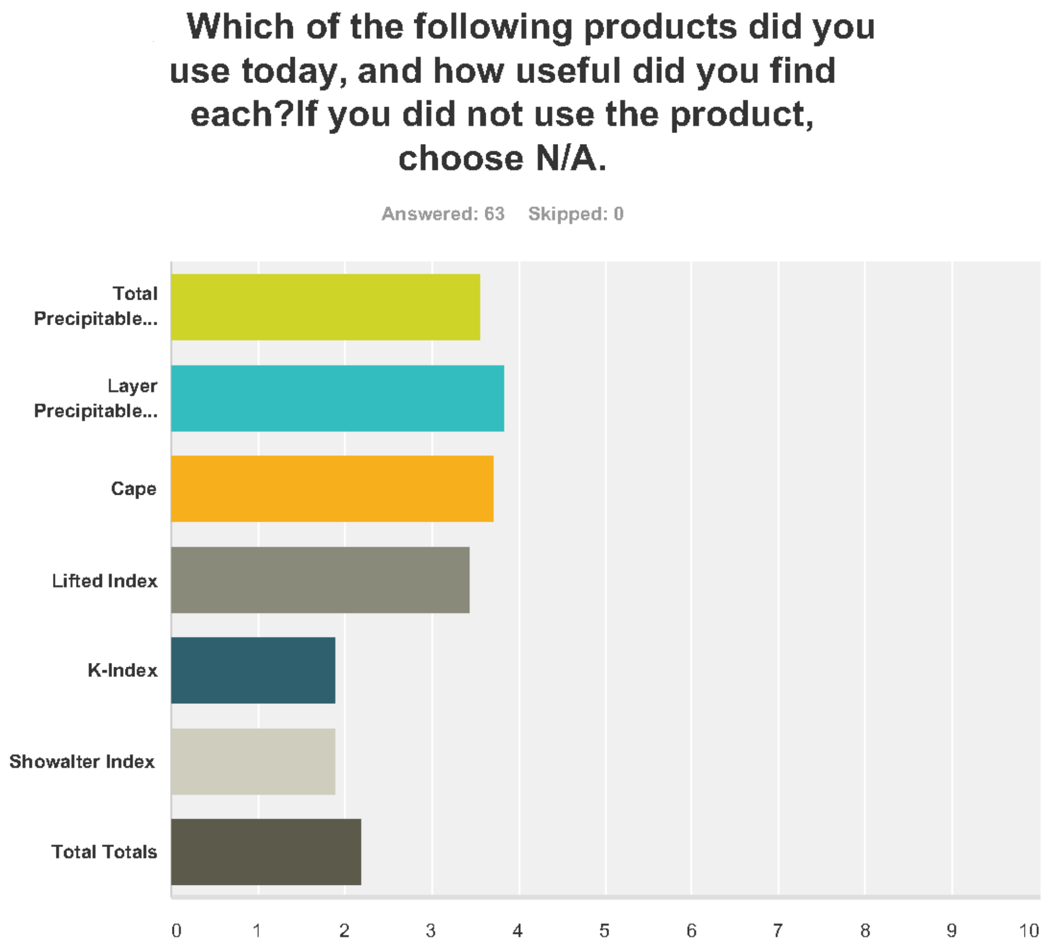


Dry line indicating storm potential.

Layered PW (LPW) from 900 hPa – SFC at 22:00 UTC on 20 April 2016, during 2016 HWT spring experiment.

Hazardous Weather Testbed (HWT) Spring Experiments Survey

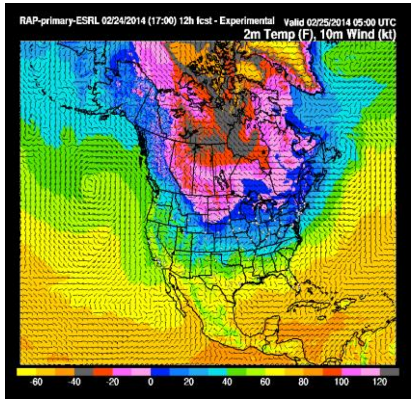




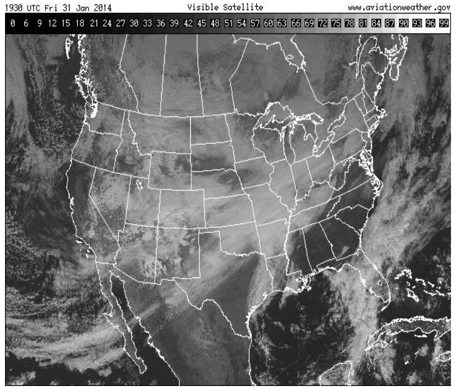
2. Using geostationary satellite imager data for local severe storm nowcasting

Problem: Converting "Big Data" to information

NWP

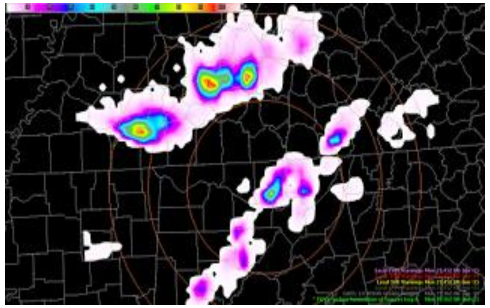


Satellite

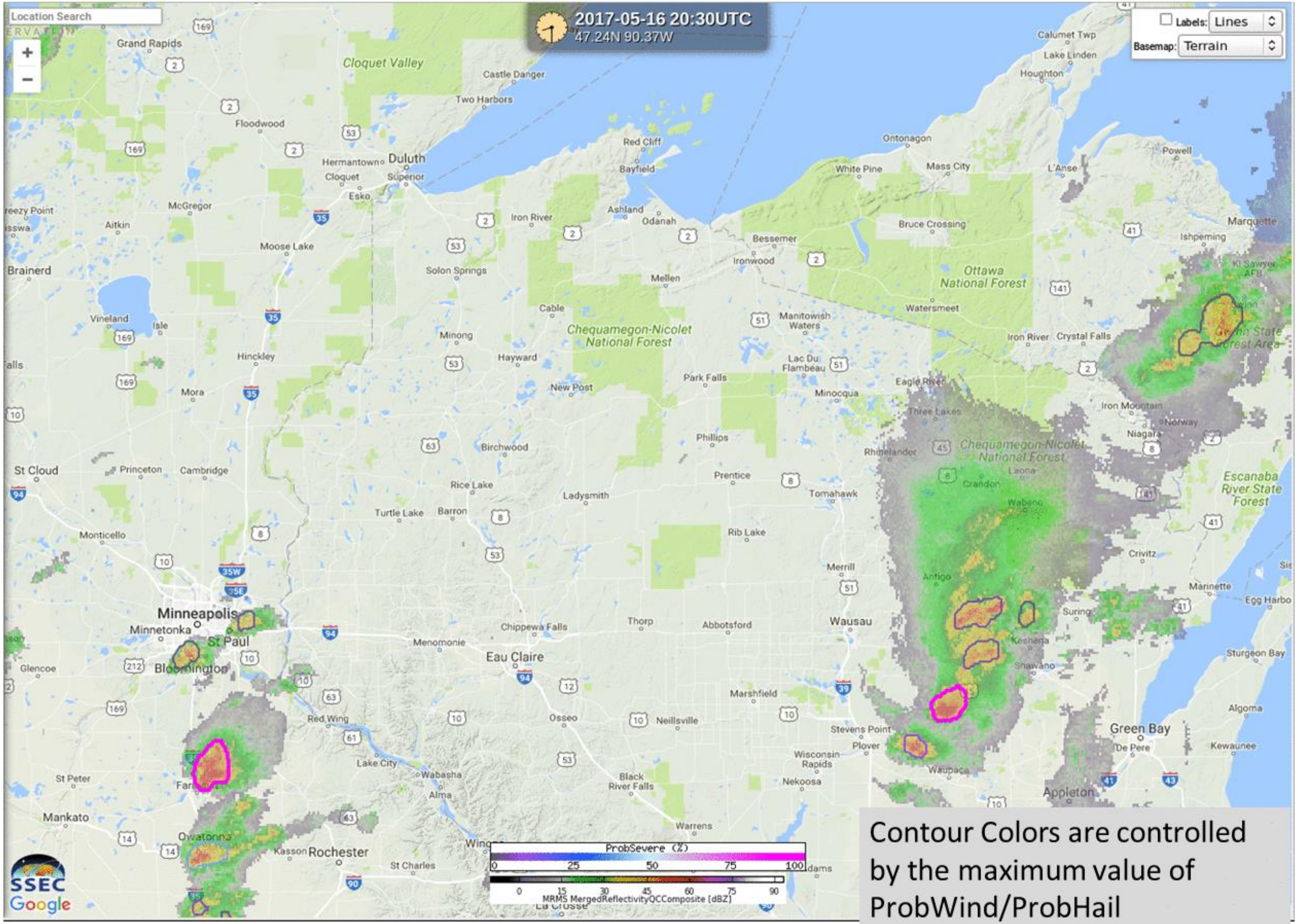


Radar

Total lightning

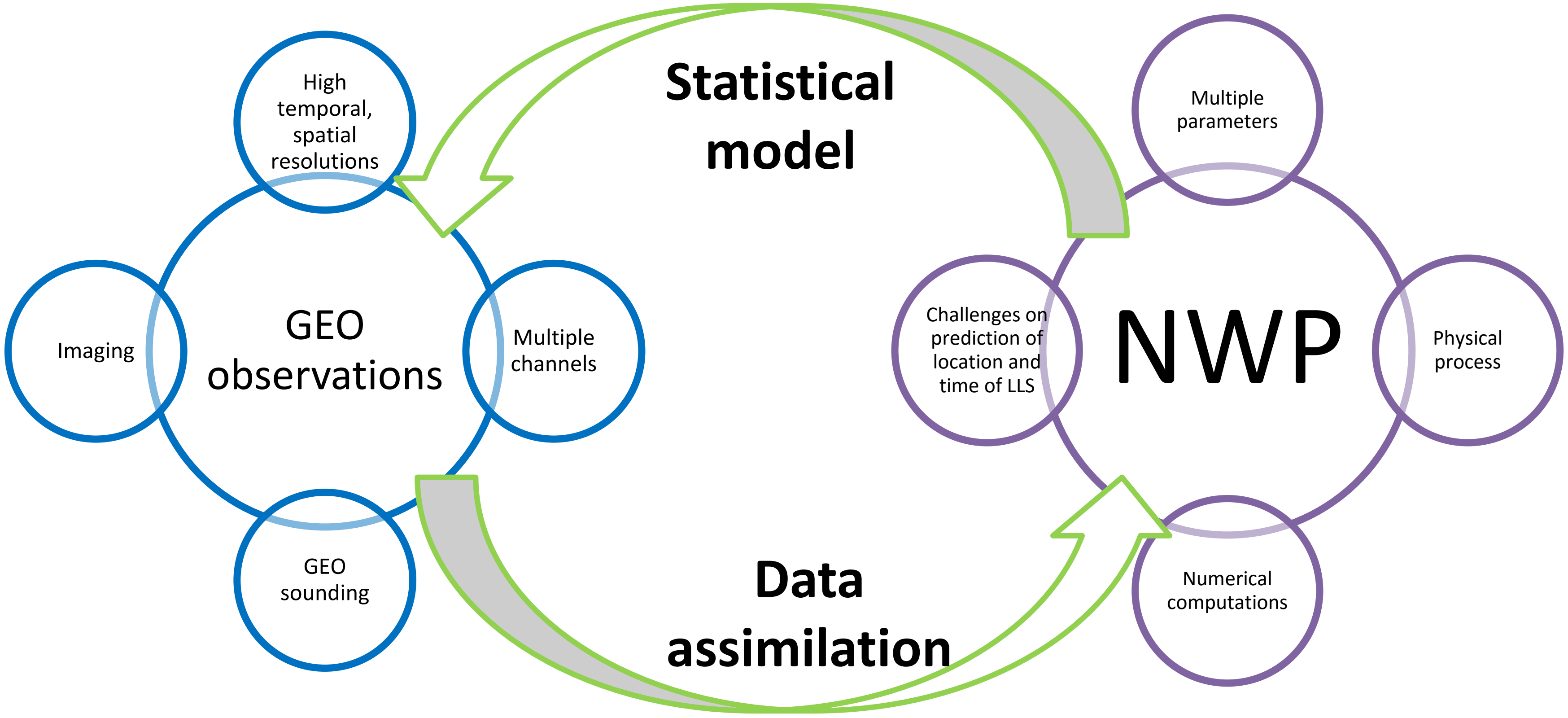


Probability a developing thunderstorm will produce severe weather in the future



Contour Colors are controlled by the maximum value of ProbWind/ProbHail

3. Local severe Storm Warning In Pre-convection Environment (SWIPE)：0 - 2 hour occurrence prediction from combined NWP model output and high resolution GEO satellite imager observations using ML technique.



- **Predictors？**
- **Satellite versus NWP ?**
- **Use of new GEO**

Data for input (satellite): GEO IR band brightness temperature (BT) observations

Himawari-8/-9 AHI

FY-4A AGRI

GOES-16/-17 ABI

GK2 AMI

Himawari-8 AHI			GOES-16/-17 ABI			FY-4A AGRI		
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Data for input (NWP): real-time short-rang forecasts from global or regional NWP models

GFS NWP	K-Index	°C
	CAPE (Convection Available Potential Energy)	$J \cdot kg^{-1}$
	CIN (Convective Inhibition)	$J \cdot kg^{-1}$
	LI (Lifted Index)	
	EBS (Effective Bulk Shear)	$m \cdot s^{-1}$
	TPW (Total Precipitable Water)	mm
	$\theta_{se850/925}$ (Pseudo-equivalent potential temperature at 850/925 hPa)	K
	PV (Potential Vorticity)	
	$Div_{925/850/10}$ (Convergence at 925 and 850 hPa/10m)	s^{-1}
	$MR_{850/925}$ (Mixing Ratio at 850/925 hPa)	$g \cdot kg^{-1}$

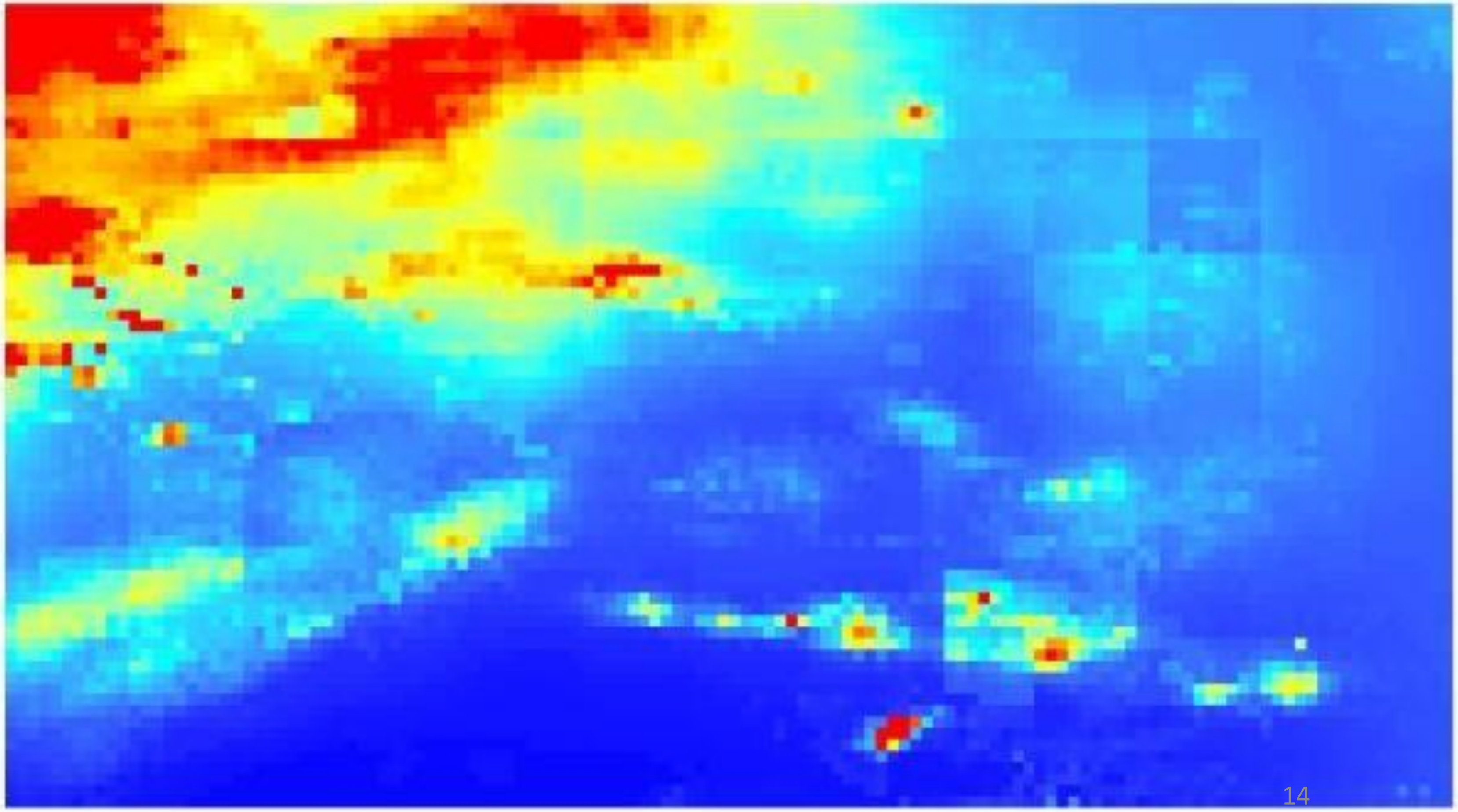
Data for label: high temporal and spatial resolution precipitation observations (label data) from fused satellite and ground measurements:

(1) IMERG – NASA GPM Level 3 product fused from microwave, infrared and ground based observations, OR

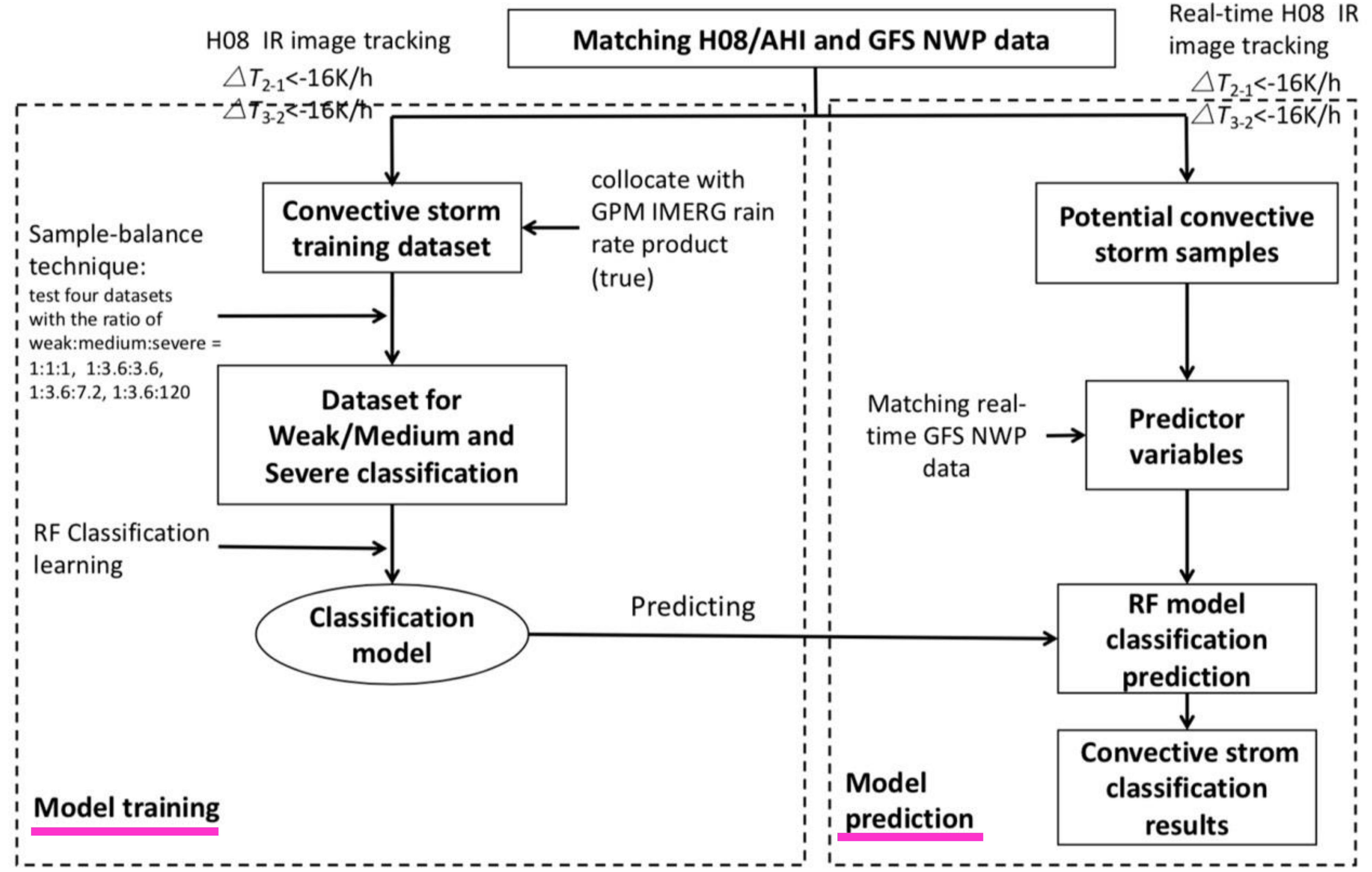
(2) CMORPH - NOAA CPC Morphing Technique (CMORPH) Global Precipitation Analyses

For LSS classification

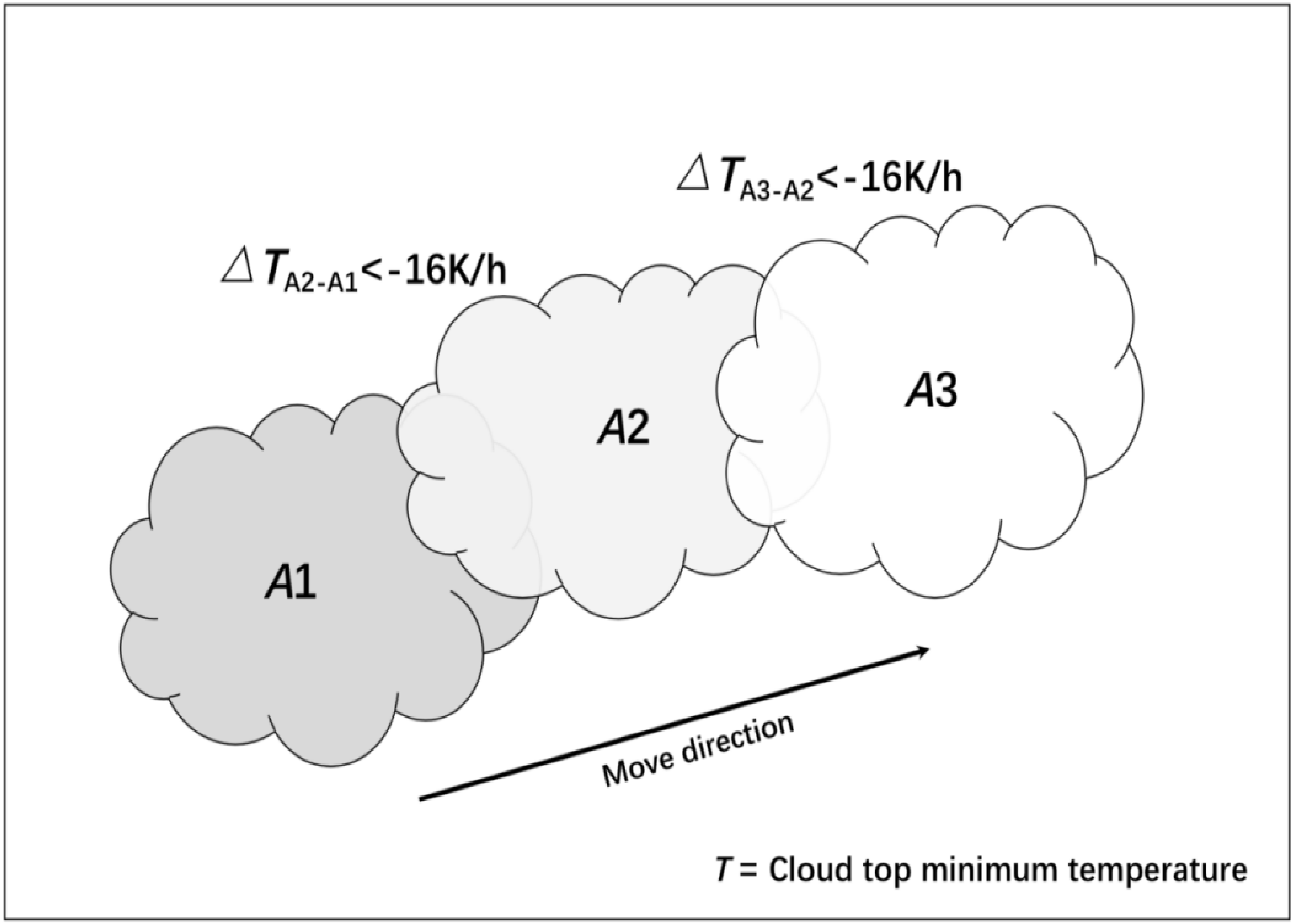
Resolution	Regions - Dates	Latency	Format	Source	DL
0.1° - 30 minute	Gridded, 90°N-90°S (* 60°N-60°S full), March 2014 to present	4 hours (NRT / Early Run)	HDF5	NRT: FTP (PPS)*	
			GIS TIFF + Wordfile	NRT: FTP (PPS)*	



Flowchart on SWIPE model: training and real-time applications

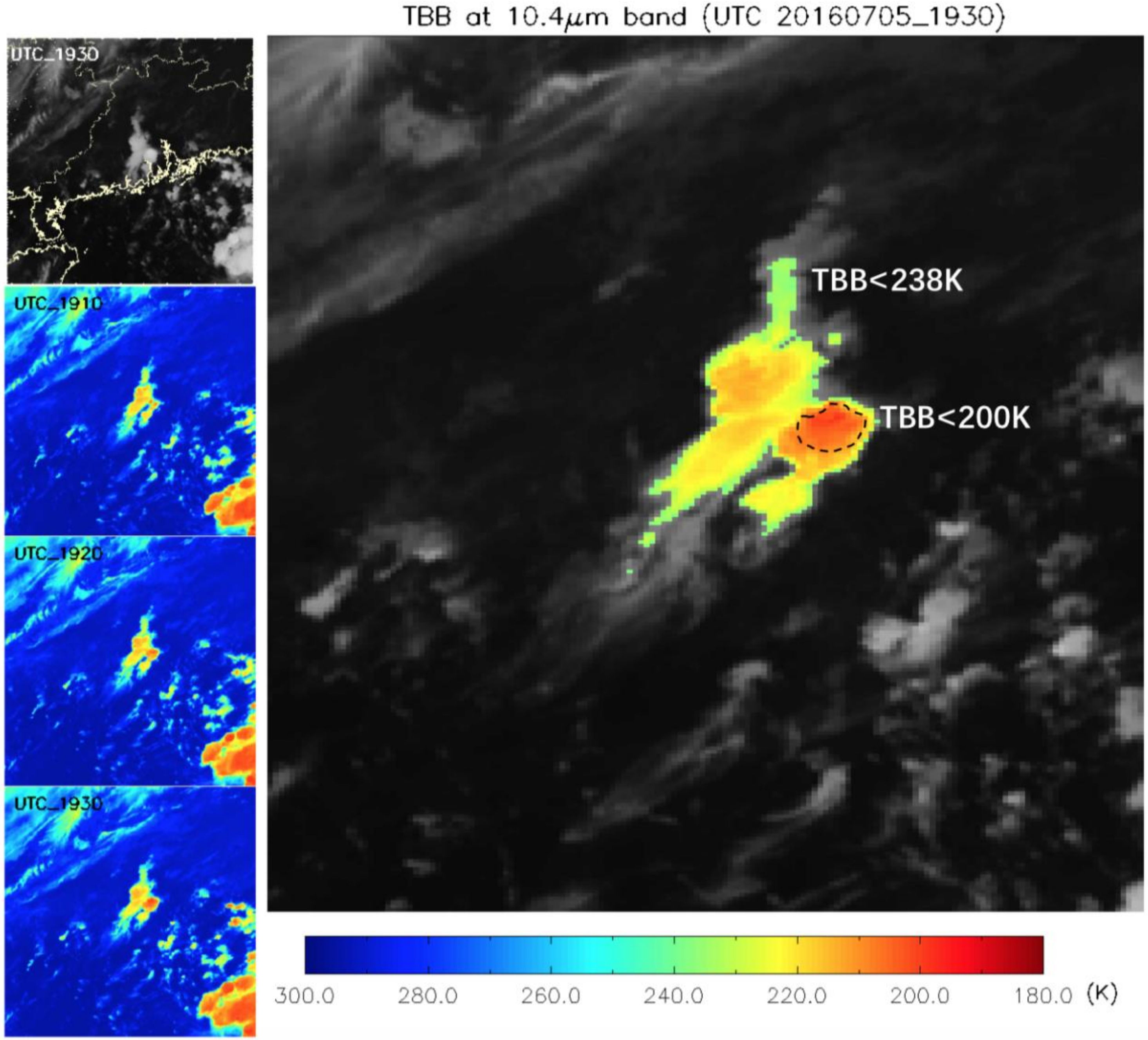


Tracking: Using the overlap area, and △T < -16K/h (Morel, 2002)

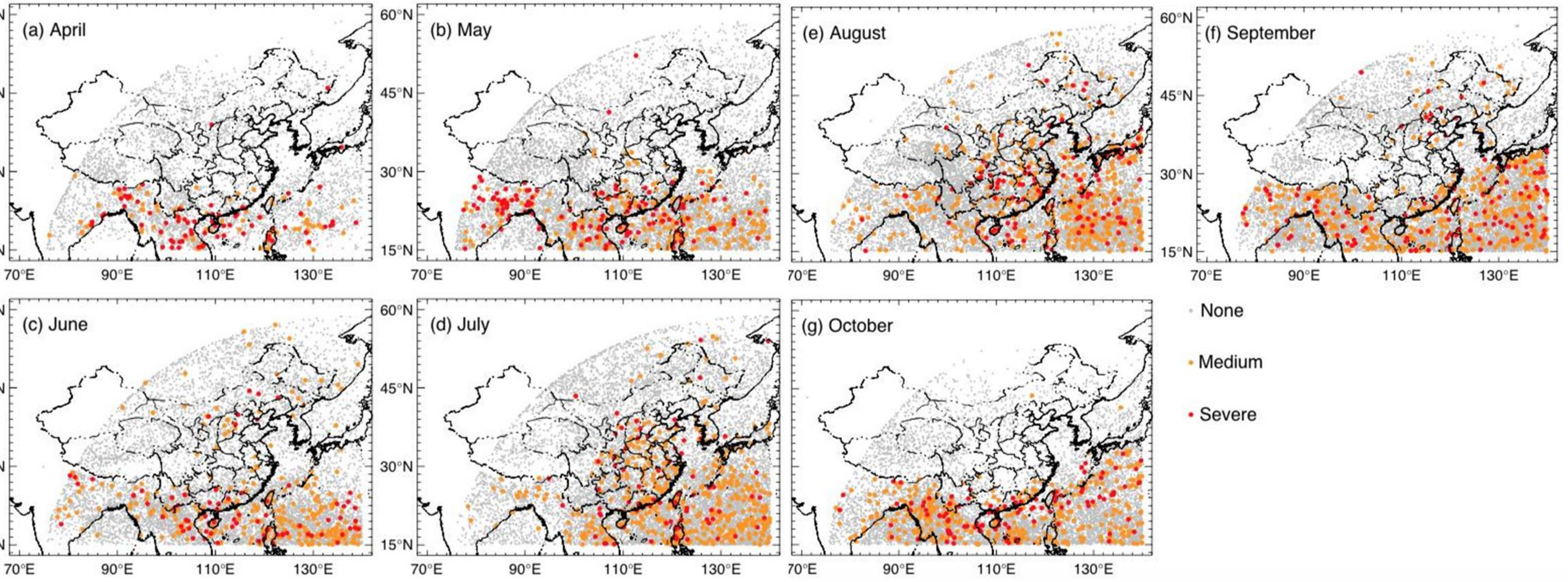


Tracking example

A real case of tracked convective storm system at 19:30 UTC on 05 July 2016 in Guangdong province of China based on H08/AHI observations. The first small sub-figure at the upper-left corner is the grayscale TBB picture at 10.4 µm band with coast line (yellow solid line). The 2-4 small colorful sub-figures at the left panel respectively represent the variation of BTs at 10.4 µm from 19:10 to 19:30 UTC. The colorful layer in the right panel represents the pixels of H08/AHI with BT<238 K at 19:30 UTC on 05 July 2016.



LSS classification: April – October 2016 tracked storm distribution



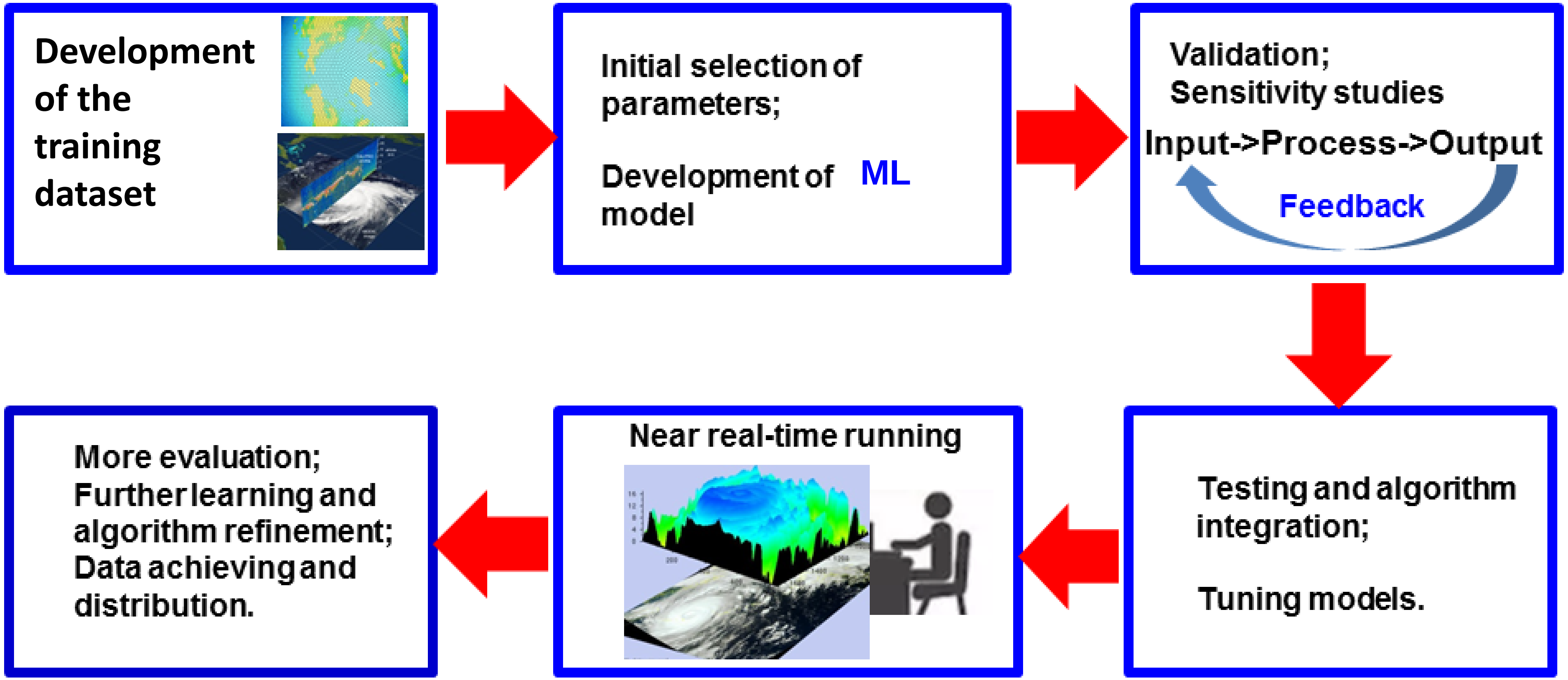
Convective types	Definition
None deep-convection	< 5 mm/h
Medium deep-convection	5 - 16 mm/h
Deep convection	> 16 mm/h

Some useful ML algorithms for nowcasting applications

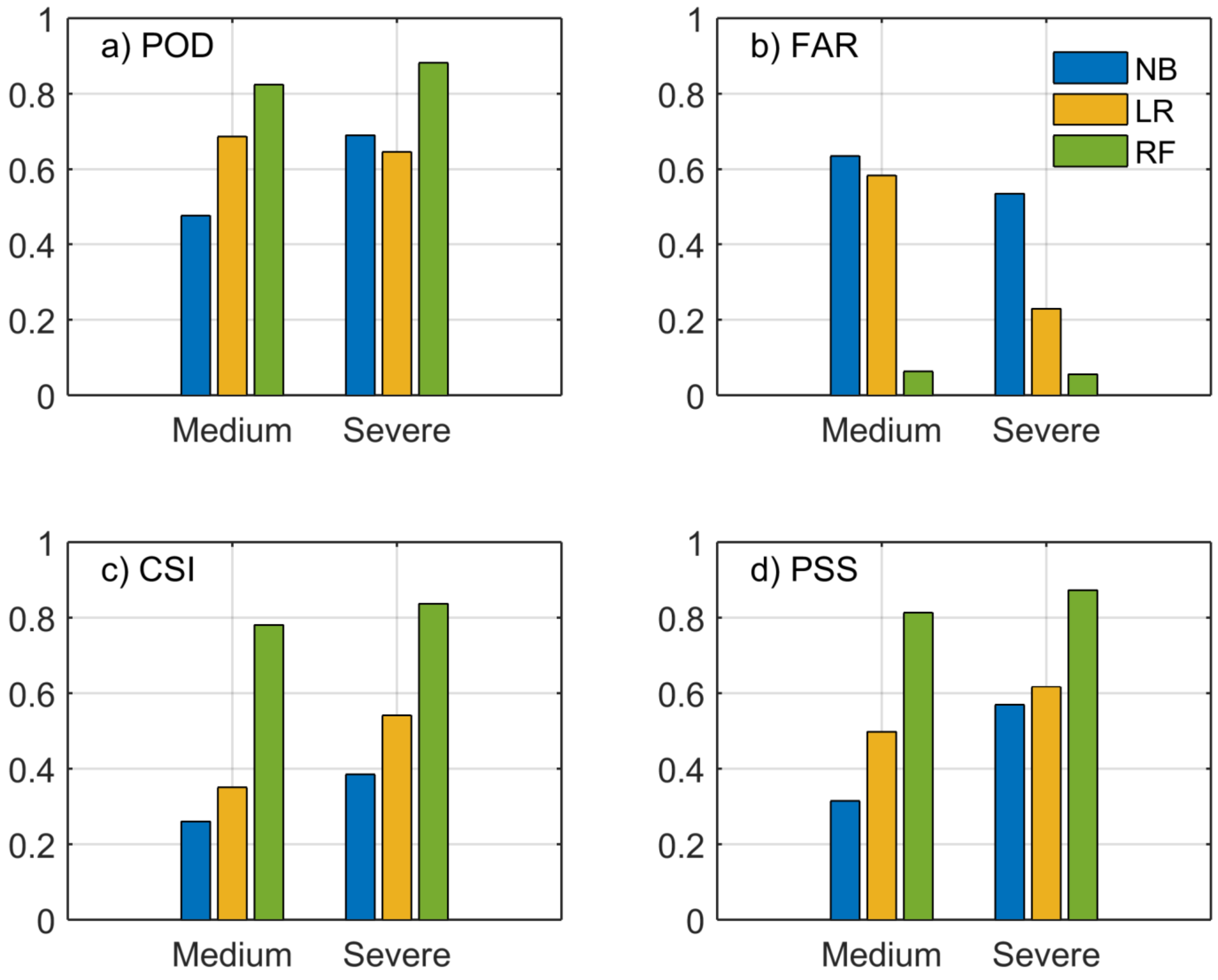
- Linear regression
- Logic regression
- Neural network
- SVM
- Knn
- K-Means
- Decision Tree
- Random forest
- AdaBoost
- Naïve Bayes
- Principal component analysis

Logic Regression (LR), Random Forest (RF) and Naïve Bayes (NB) are tested for SWIPE

Technical approaches for developing and application of SWIPE



Evaluation of three ML models - scores



POD: Probability Of Detection (or Hit Rate)

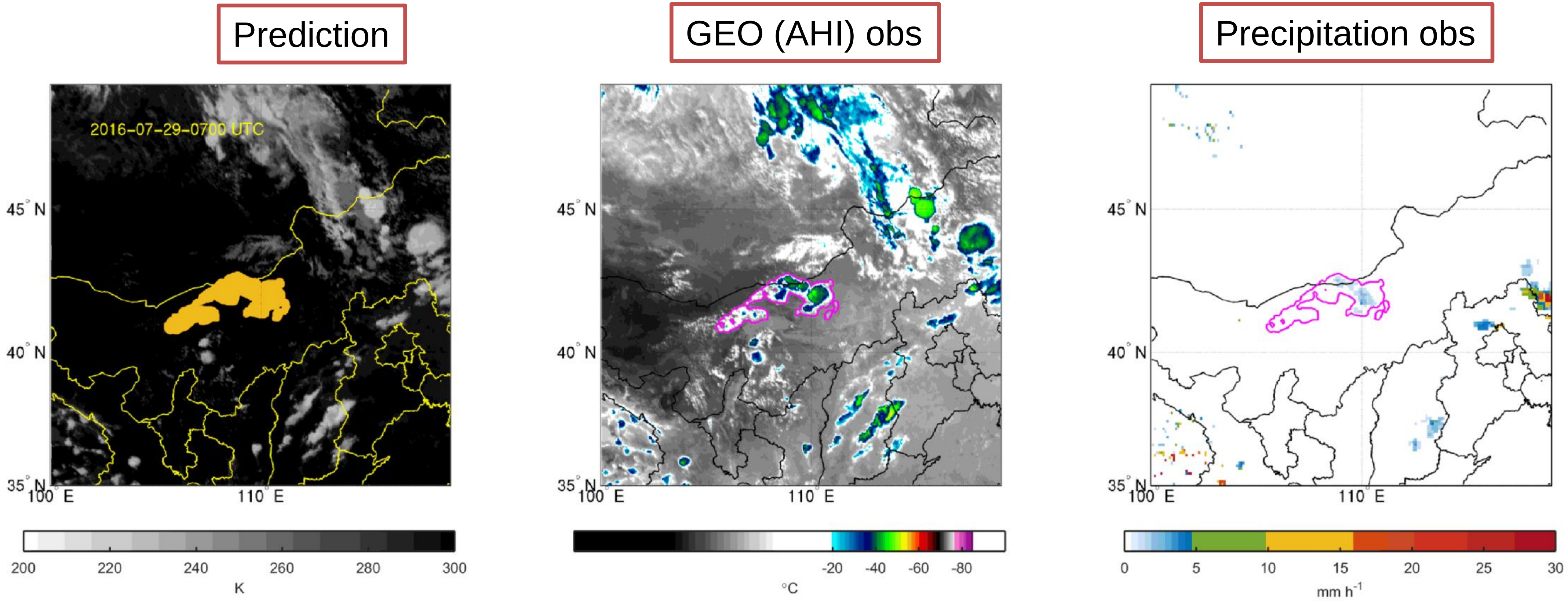
FAR: False Alarm Ratio

CSI: Critical Success Index or equation for threat score

PSS: Peirce Skill Score

RF has the best performance, and Prediction of deep convection is better than prediction of other types of storms.

Comparison example (29 July 2016) – three ML models



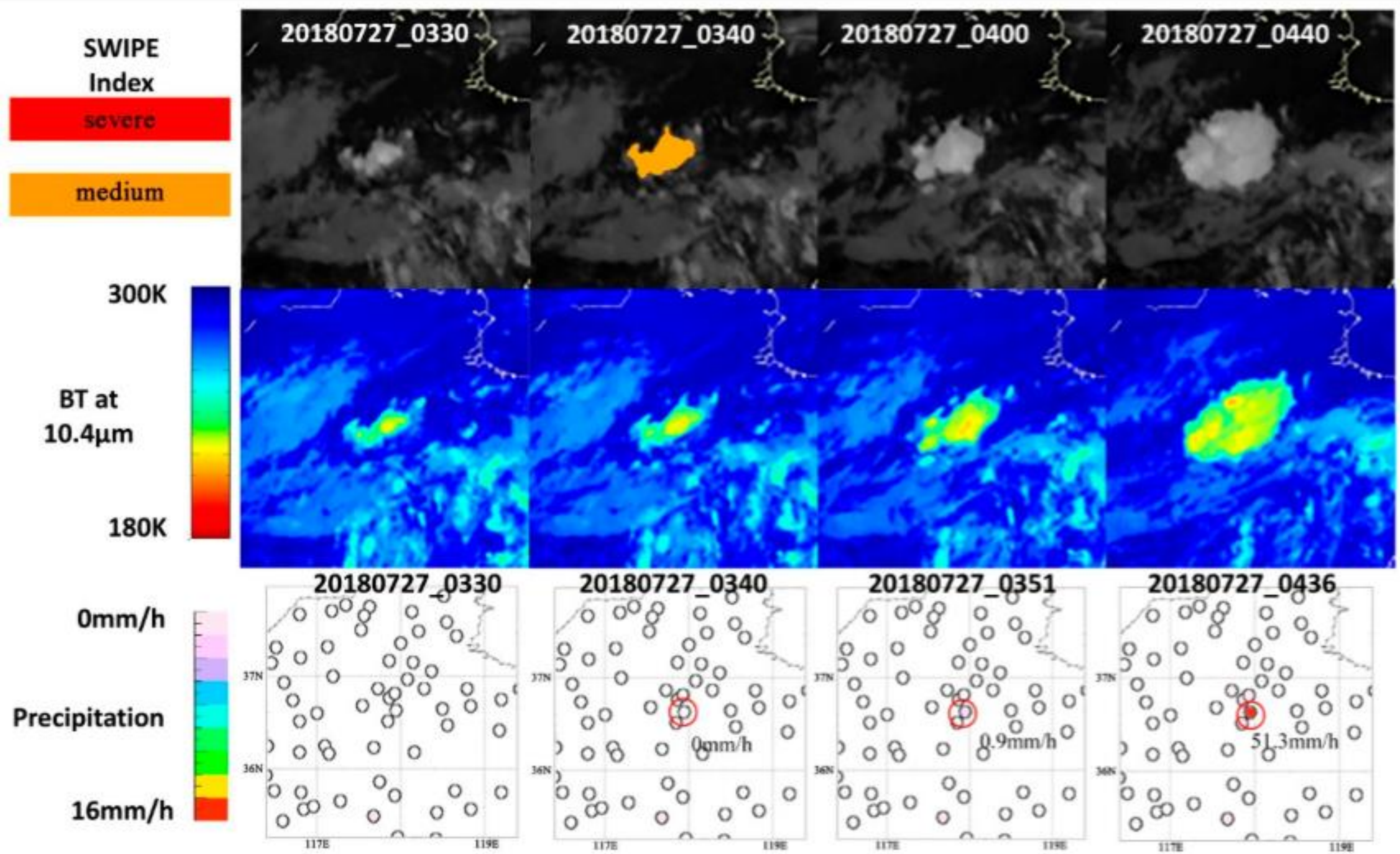
- **0700 UTC (Yellow): RF (earlier than other methods)**
- **0900 UTC (Red): LR (later than RF, earlier than NB)**
- **1030 UTC (Purple): NB (later than RF and LR)**
- **1200 UTC: Rain rate > 16 mm/h**

RF is selected for SWIPE - predictor ranking base on sensitivity study

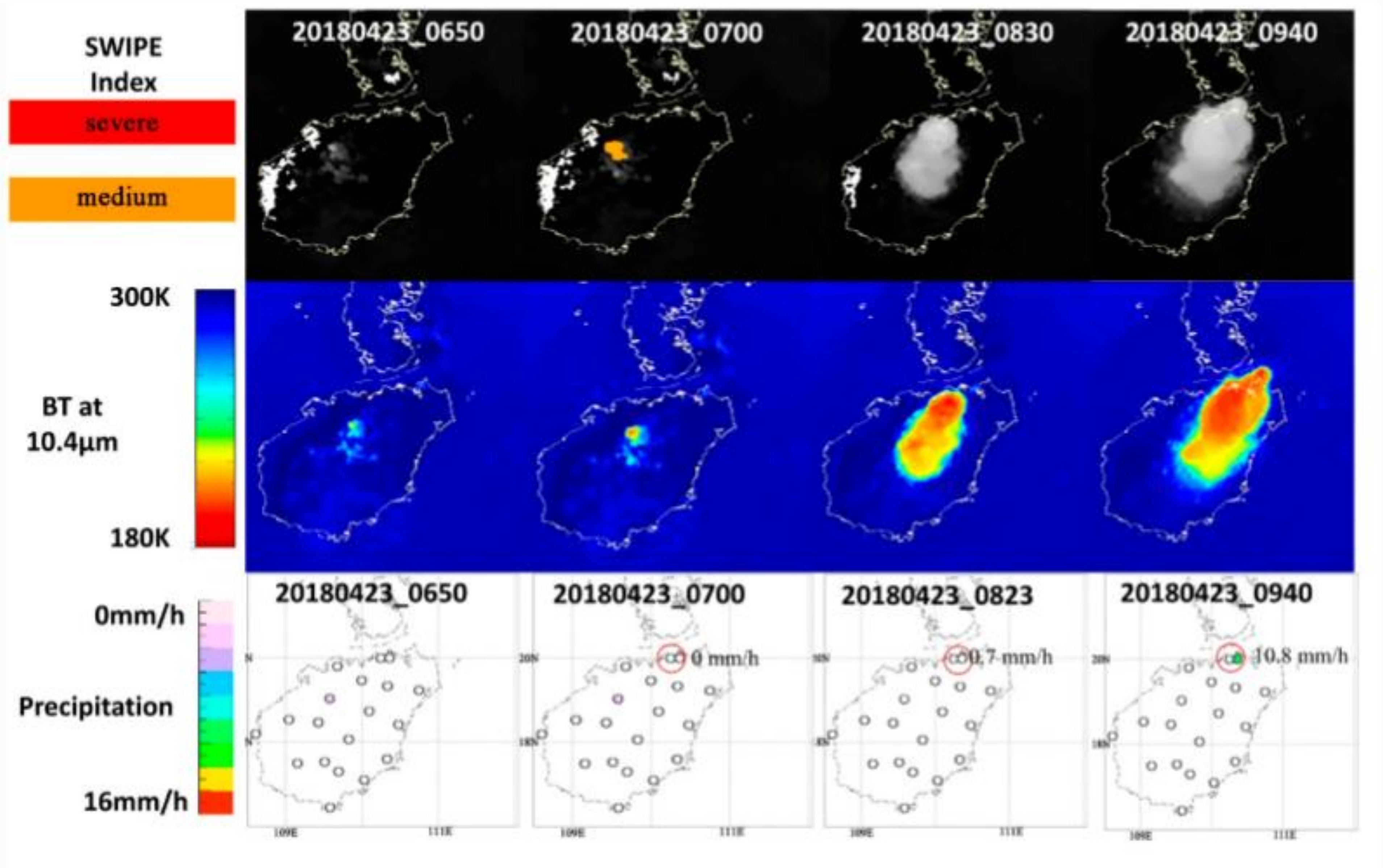
	All predictors		GEO		NWP	
Ranking	Scores	Variables	Scores	Variables	Scores	Variables
1	3.07	Div10m_mean	6.67	Area	3.88	Div10m_mean
2	2.99	Div850_mean	5.61	PR_max	3.49	Div925_mean
3	2.76	Div10m_max	3.99	Tb1040_min	3.24	Div850_mean
4	2.74	PR_max	3.33	Tb_tr	3.01	Kind_min
5	2.65	Div10m_min	3.22	Tb1040_mean	2.88	TPW_min
6	2.61	Div925_mean	3.19	Tb1040_max	2.78	Θse850_min
7	2.58	CIN_mean	3.03	dTb73_min	2.74	Θse850_mean
8	2.49	TPW_min	3.02	dTb62_min	2.68	MR850_min
9	2.43	MR850_min	2.96	dTb73_max	2.67	PV_mean
10	2.39	TPW_mean	2.81	PR_mean	2.64	TPW_mean

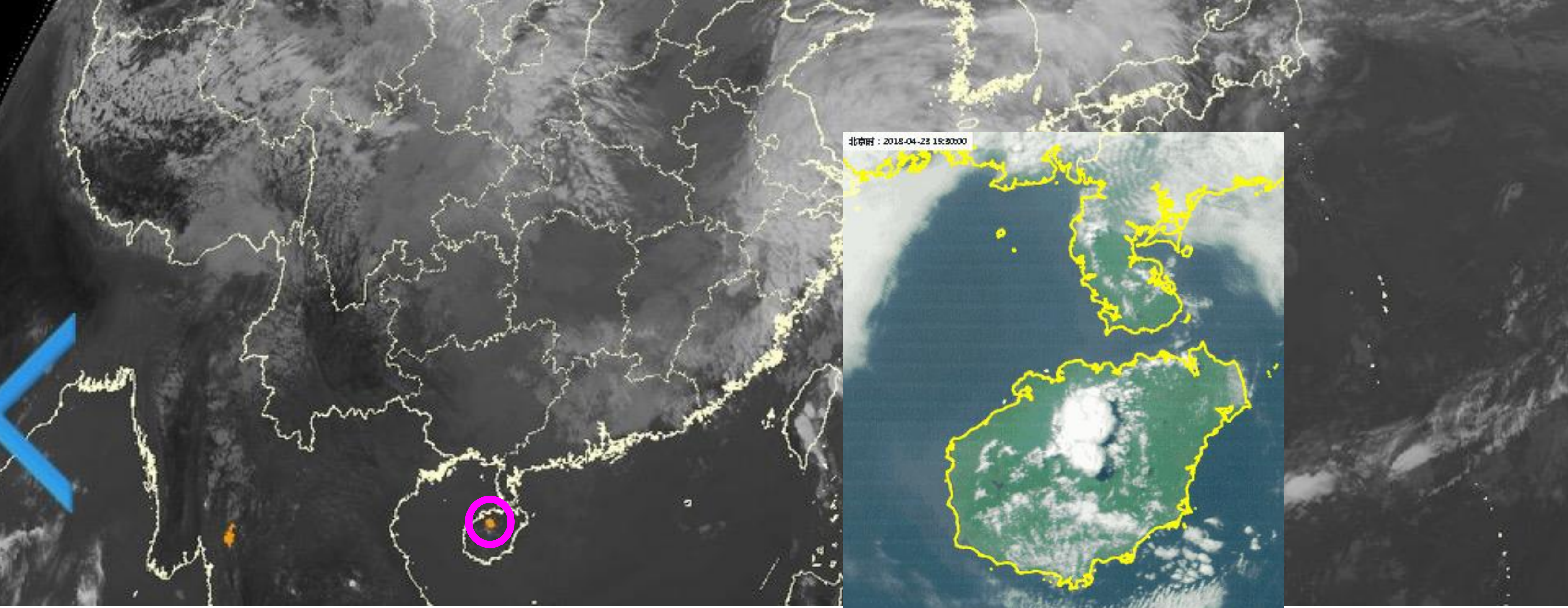
4. Application examples: from real-time SWIPE system

Case A: A sudden convective storm case at 03:40 UTC on 27 July 2018 in Shandong province.



Case B: A sudden convective storm case tracked by the SWIPE model at 07:00 UTC on 23 April 2018 in the Hainan Province.

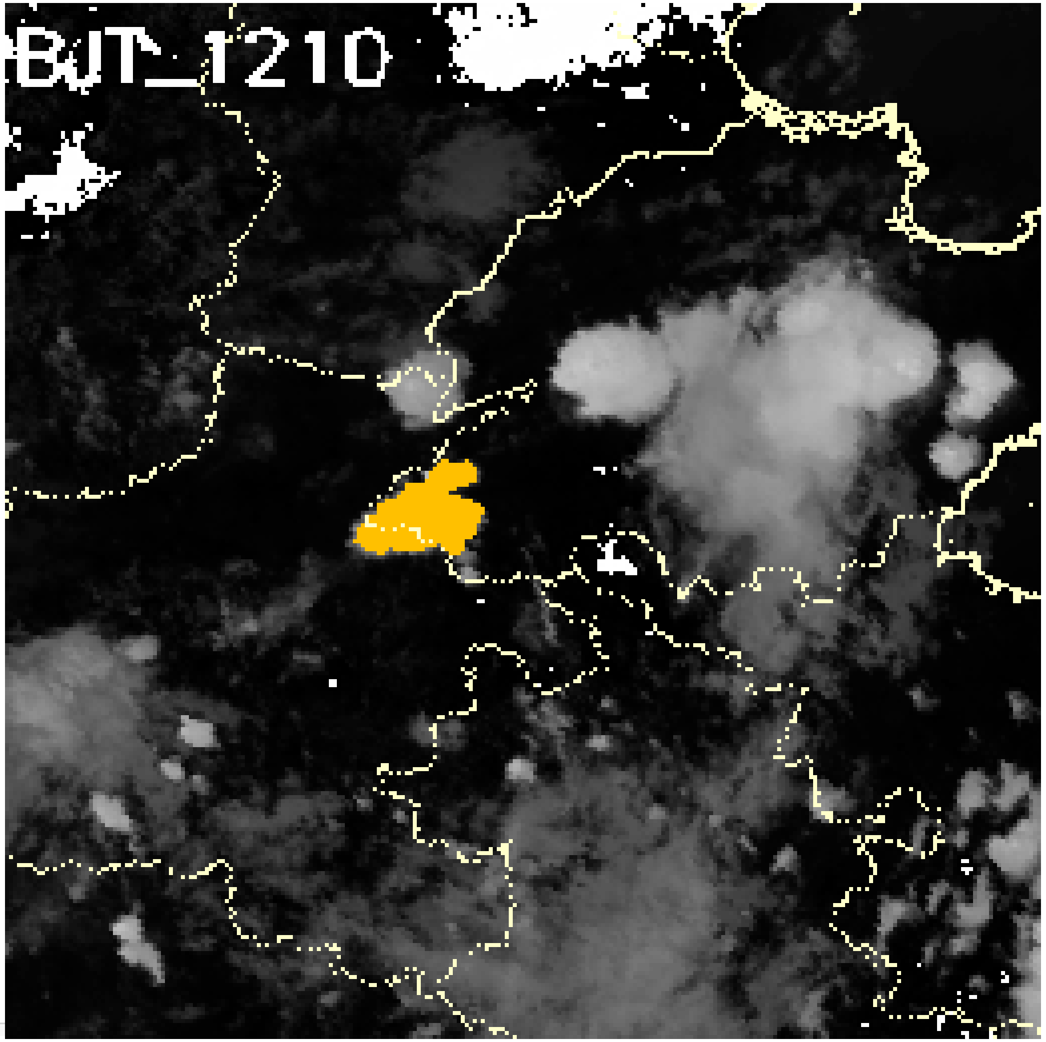




SWIPE detects at 07:00 UTC in pre-convection, rain starts at 08:30 UTC

Case C: 26 July 2018 , flight GS7865 (Tianjin Airlines A320 hit by severe hail storm.

SWIPE detects this storm 3 hours ahead of occurrence.



Case d: 11 April 2019
Shenzhen Storm

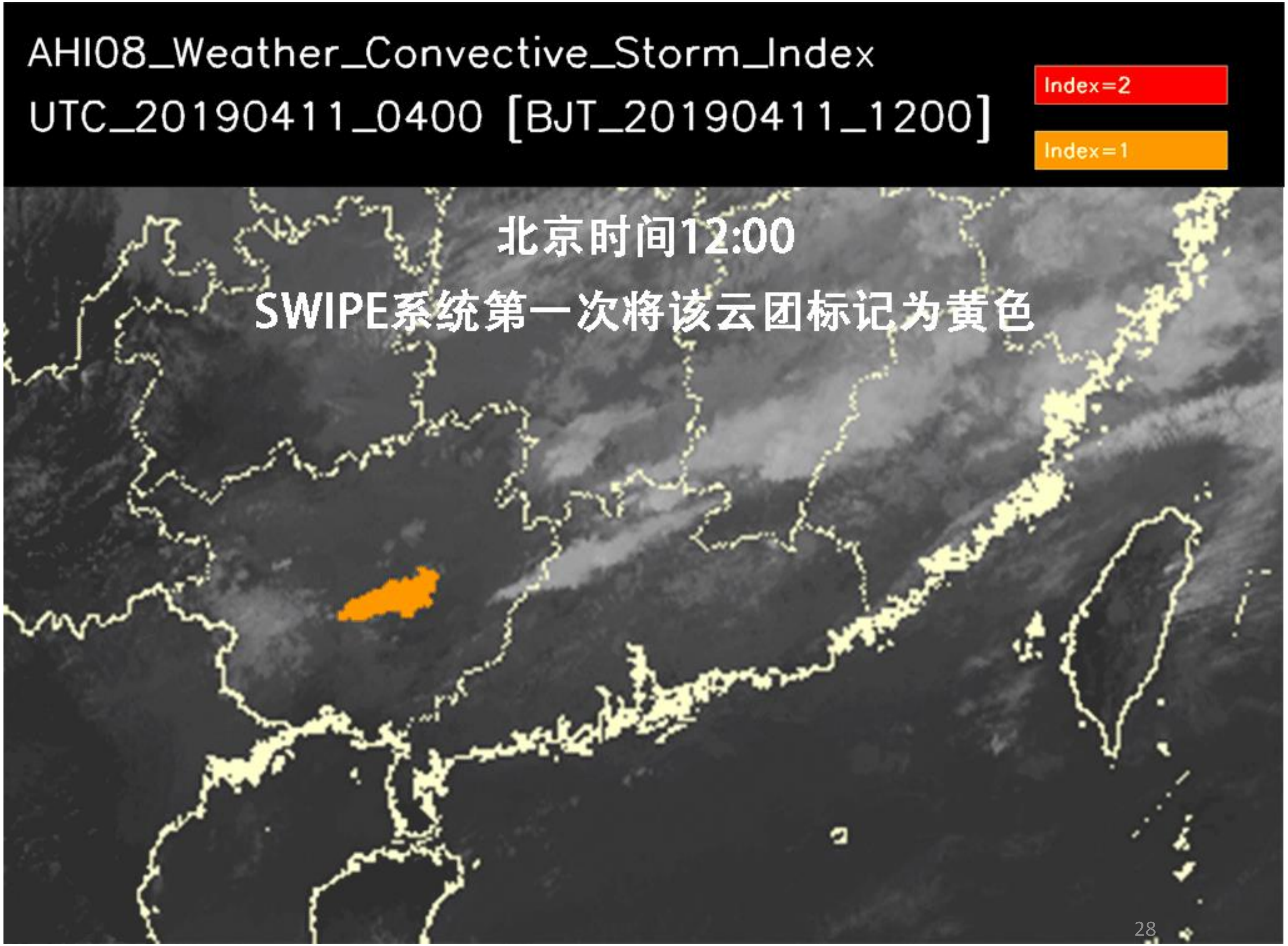
BJT 12:00 Yellow

BJT 12:50 Red

BJT 15:30 Yellow

BJT 19:25 Warning was issued by weather service

BJT 21:40 50mm/h precipitation was observed



5. Summary and future work

- GEO imager measurements can be applied in nowcasting through object detection, real-time nowcasting product generation, statistical prediction model, and data assimilation in storm scale NWP.
- A convective storm occurrence prediction model has been developed using Machine Learning (ML) technique, based on combined high spatial-temporal resolution GEO imager and short-range NWP data. Precipitation observations are used to classify the severity of the storm occurred for training purpose;
- Both types of data play important role in the model but satellite data are more important;
- Since the storms have regional characteristics, the ranking of each parameter also depends on the region, therefore it is important to develop regional ML models for regional users;
- Future work will include more data (e.g., surface obs as additional input and radar for label) in SWIPE, develop regional SWIPE, include GEO hyperspectral IR sounder data such as GIIRS measurements.

Reference:

Liu, Z., M. Min, Jun Li, F. sun, D. Di, Y. Ai, Zhenglong Li, D. Qin, G. Li, Y. Lin, and X. Zhang, 2019: Local Severe Storm Tracking and Warning in Pre-Convection Stage from the New Generation Geostationary Weather Satellite Measurements, Remote Sensing. 11(4), 383.