An innovative landslide warning system based on hybrid rainfall monitoring using satellite and ground weather radar

April, 2019

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Outline

- Background
  - ✓ Increase of heavy rainfall induced landslide by climate change
  - ✓ Importance of nation-wide accurate rainfall monitoring for landslides early warning in developing countries

- Methodology
  - ✓ Operational system in Japan based on ground radar and RBFN (a machine learning approach)
  - ✓ Hybrid rainfall monitoring using ground radar and satellite sensors

- Case study
  - ✓ Research activities and prototype in the Philippines

Increase of heavy rainfall induced disasters by climate change

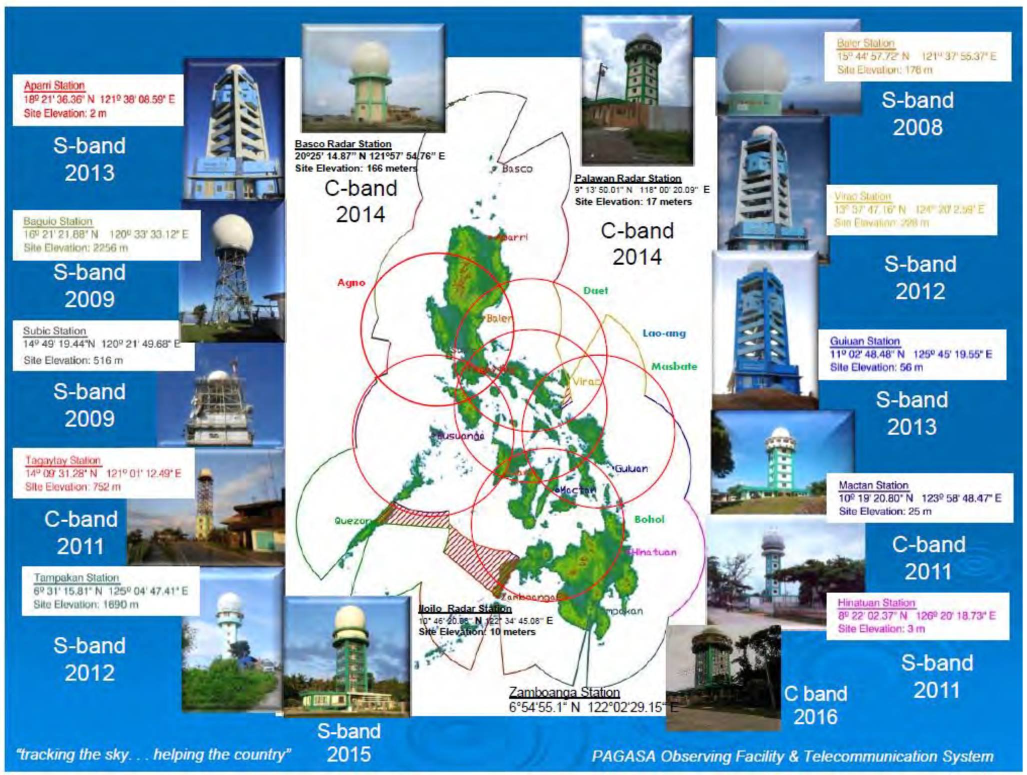
Cordillera Region in the Philippines, September 14, 2018

- ✓ On September 14, 2018, at about 1:00 AM, Typhoon Ompong (International Code Name Mangkhut) passed through the Cordillera Region.
- ✓ The typhoon brought heavy rains and strong winds with speeds of up to 265 kph that caused widespread damage to agriculture, shelter and infrastructure. There were also numerous reported casualties.
- ✓ A total of 119 landslides and 33 flooding incidents were reported in the region. These landslides caused road closures shelter damage, damage to livelihood, and casualties.
- ✓ As of 1800H of September 17, 2018, fifty four (54) were reported dead, thirty two (32) were injured and forty eight (48) are still missing. These numbers are expected to rise as the search and rescue operations are still ongoing.

Source: the Cordillera Disaster Response and Development： http://cordisrds.org/

Importance of nation-wide accurate rainfall monitoring

- Increase of heavy rainfall induced disaster damage by climate change
  : Still lack of infrastructure against disaster especially in developing countries
- Improvement needs of “software approach” in addition to “hardware approach”.
  : More accurate, effective and earlier warning information
- Installment of ground weather radar in developing countries
  : Operational issues on maintenance, calibration and coverage



PAGASA’s ground weather radars

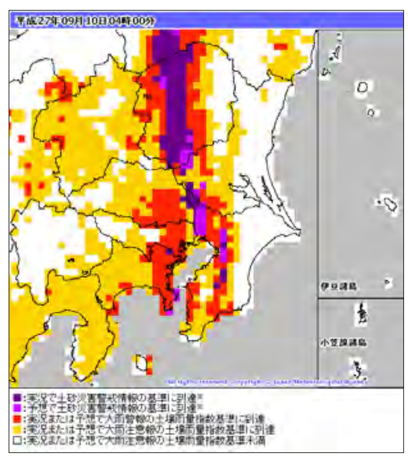
Operational system in Japan based on ground weather radar and RBFN (a machine learning approach)

Non-structural measures in Japan:

There are 2 ways for reducing human suffering from landslide disasters.

1. Designating hazard areas based on the landslide disaster prevention law

2. Issuing “Early Warning Information”



Operational Landslide Warning System in Japan

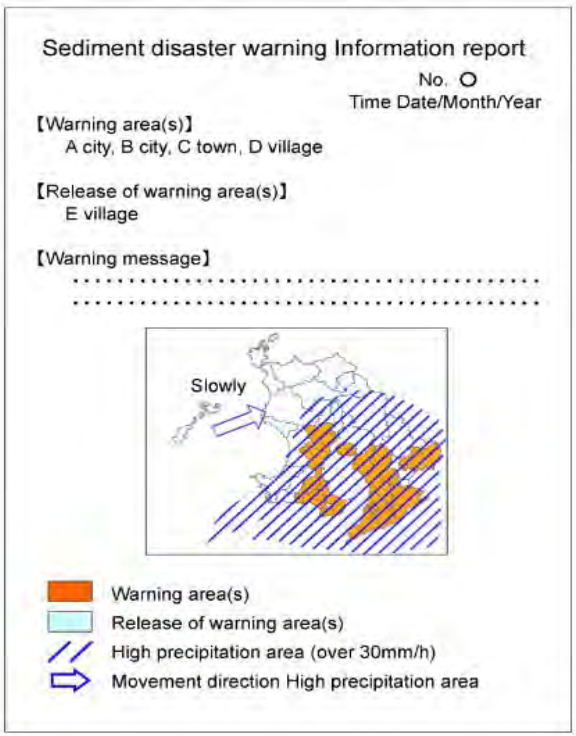
Prefectural government and meteorological observatory (JMA) cooperated to issue early warning information in 2006 using Ground Radar and RBFN methodology.

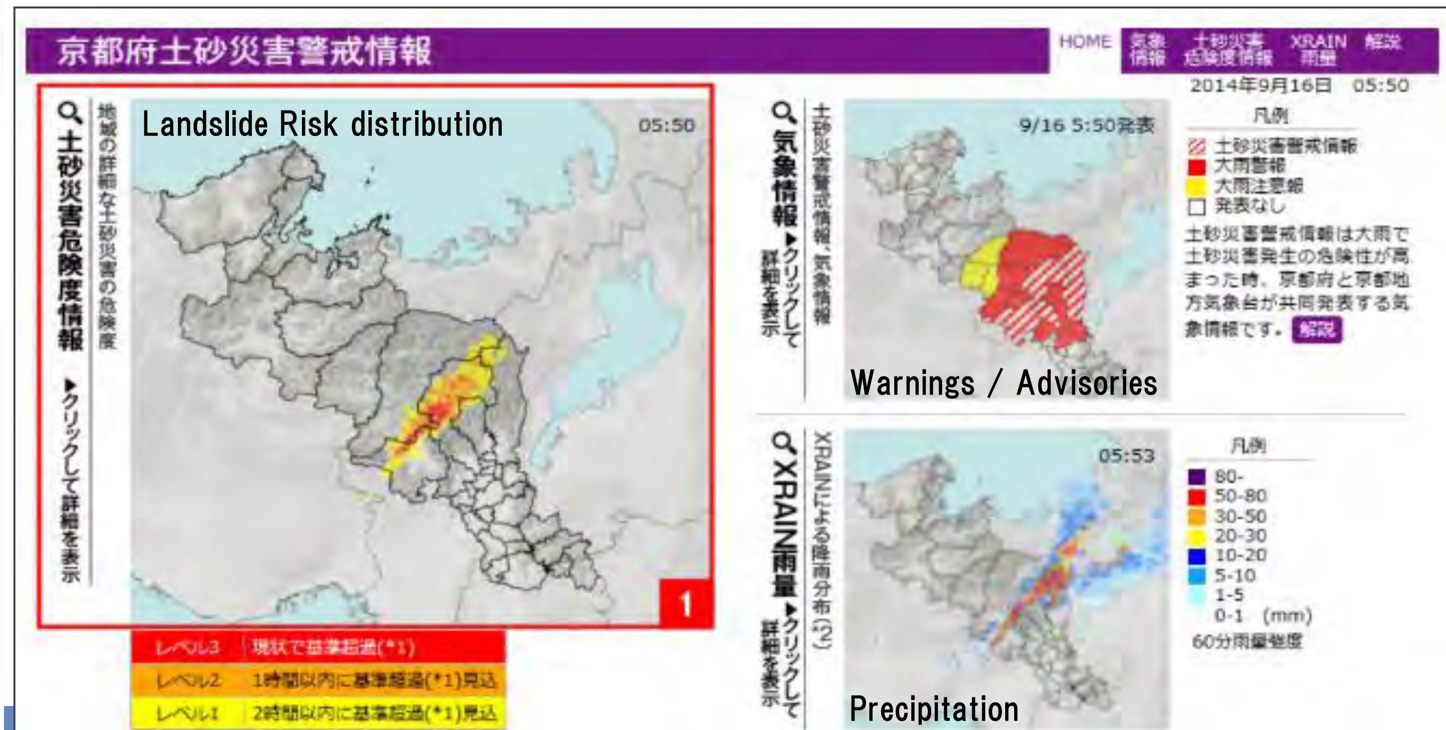
Prefectural government

- Surveying landslide hazard area
- Setting rainfall criteria for giving an early warning

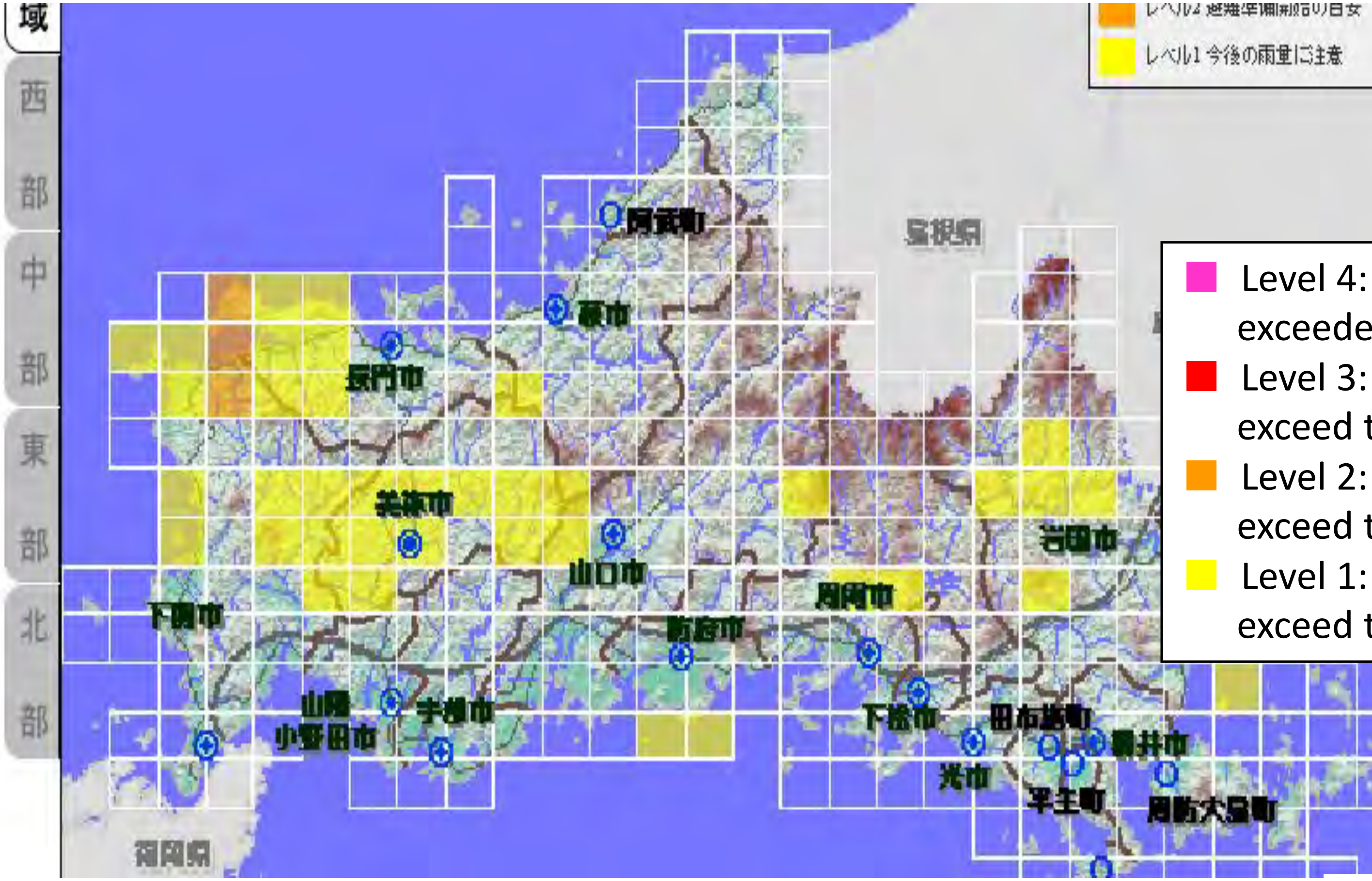
Local meteorological observatory

- Rainfall observation
- Providing meteorological information through medias

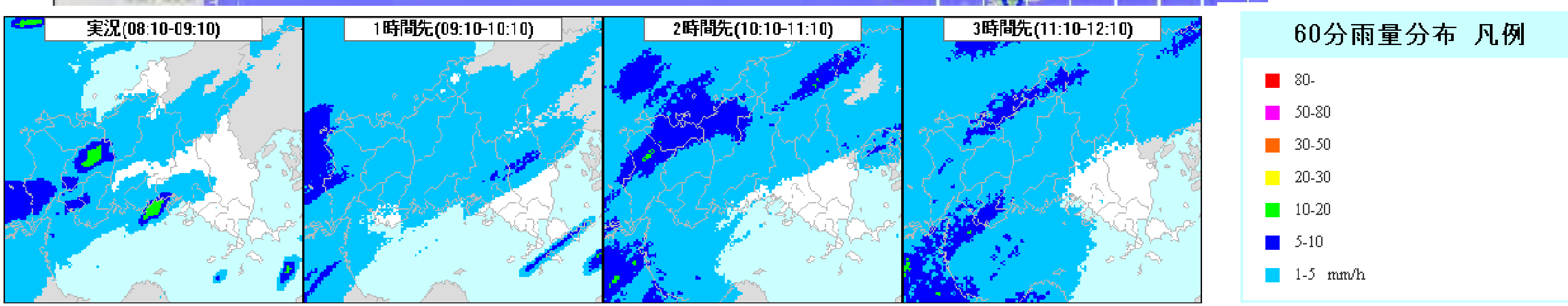




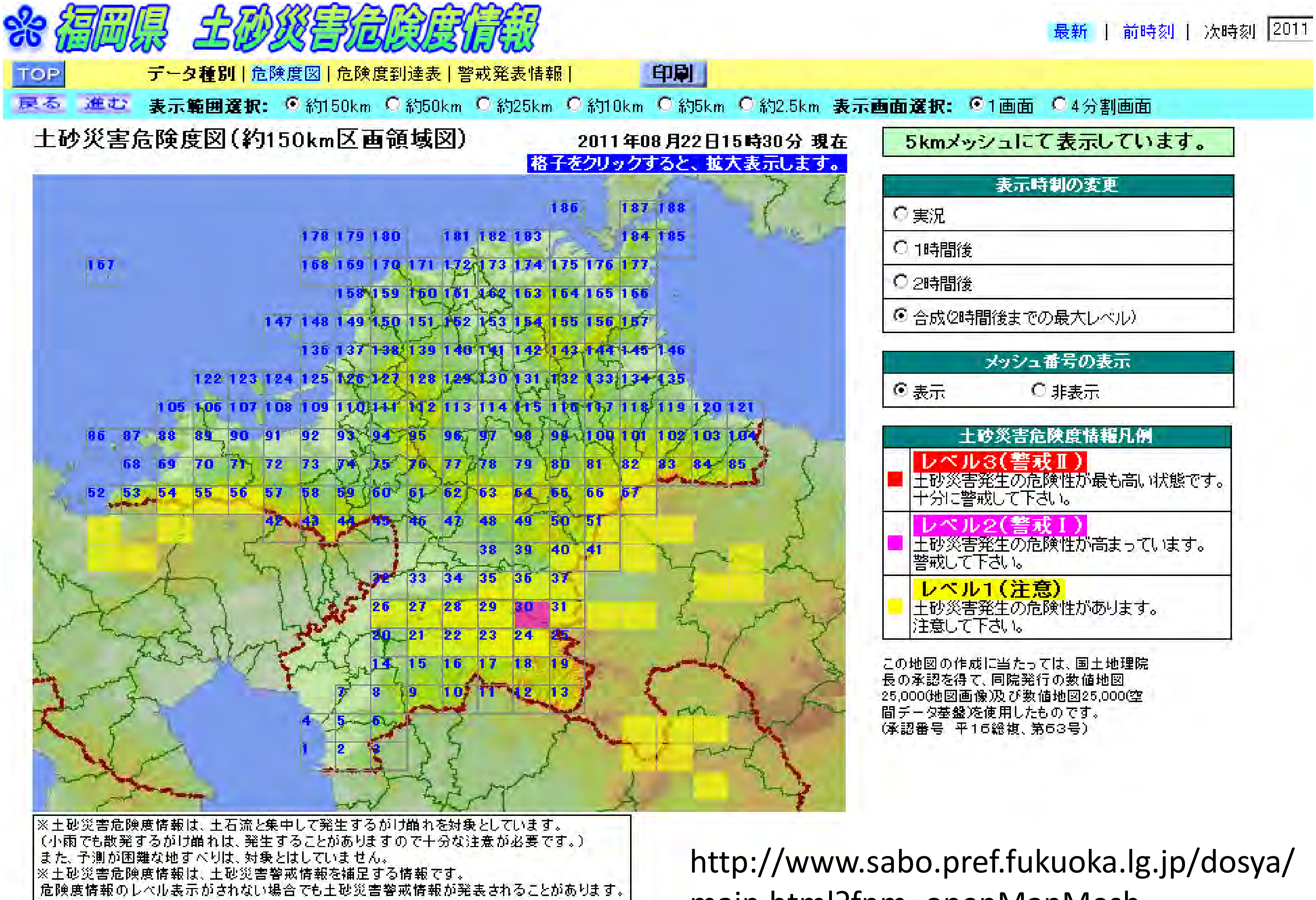
Early warning support system in Yamaguchi prefecture



- Level 4: Snake line already exceeded the CL
- Level 3: Snake line will exceed the CL in 1 hours
- Level 2: Snake line will exceed the CL in 2 hours
- Level 1: Snake line will exceed the CL in 3 hours



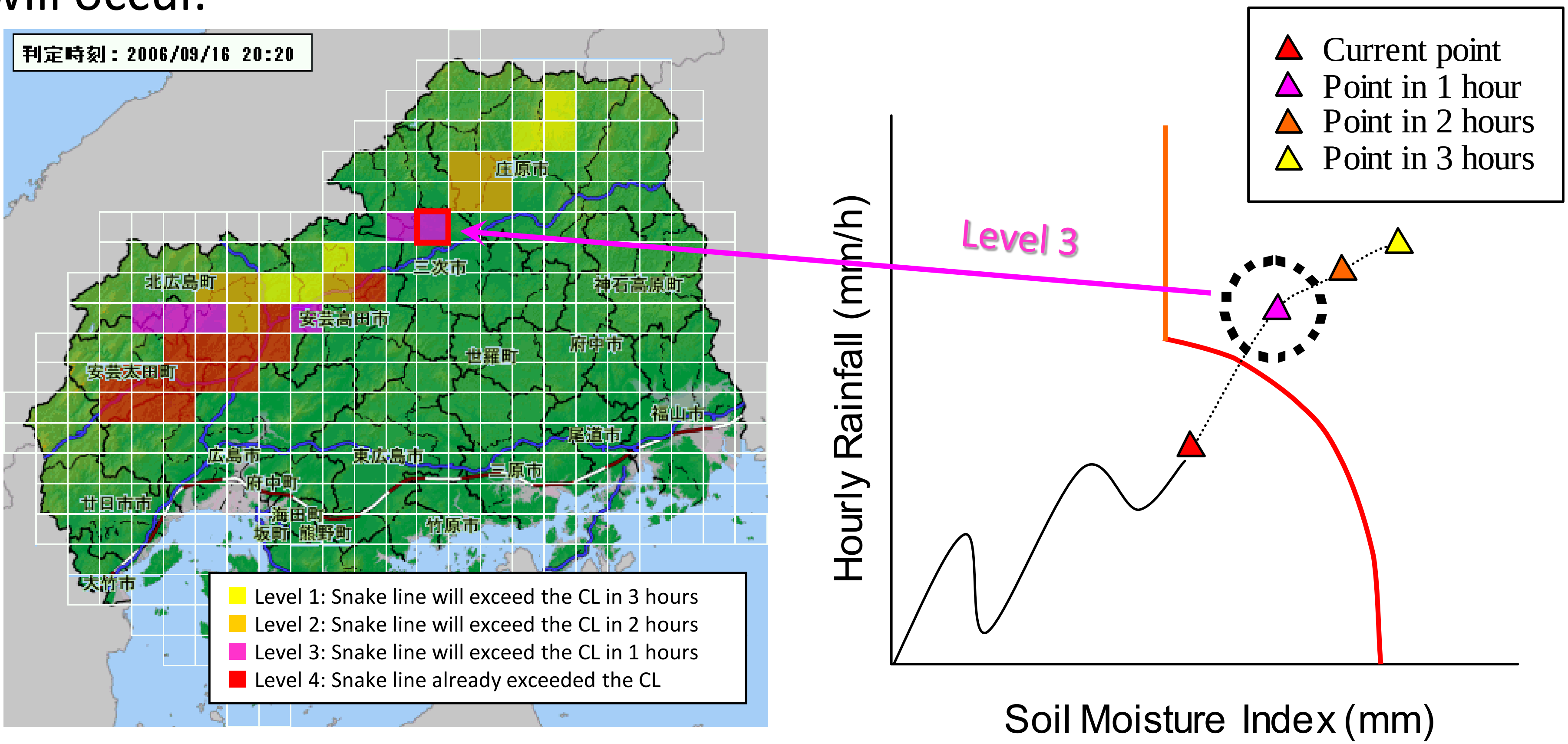
Early warning support system in Fukuoka prefecture



http://www.sabo.pref.fukuoka.lg.jp/dosya/main.html?fnm=openMapMesh

Provide risk of landslide disaster using an early warning support system

The system can provides the details of “when” and “where” disasters will occur.



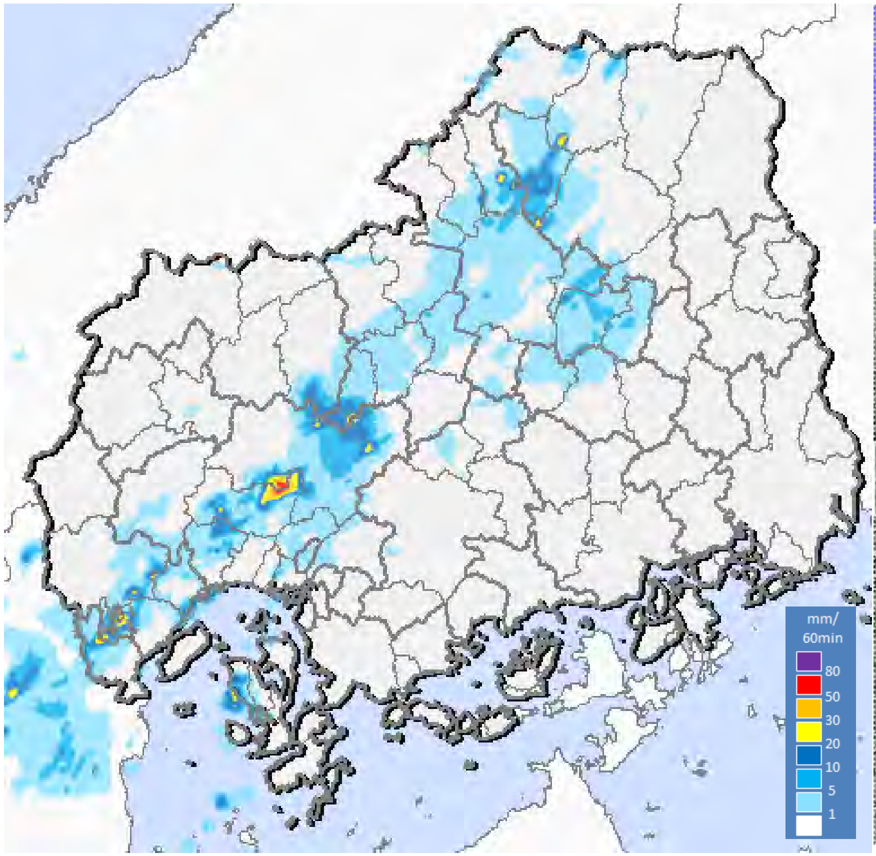
It is important to develop an early warning support system so as to operate the early warning information efficiently.

Damage Situation of Hiroshima Disaster 2014

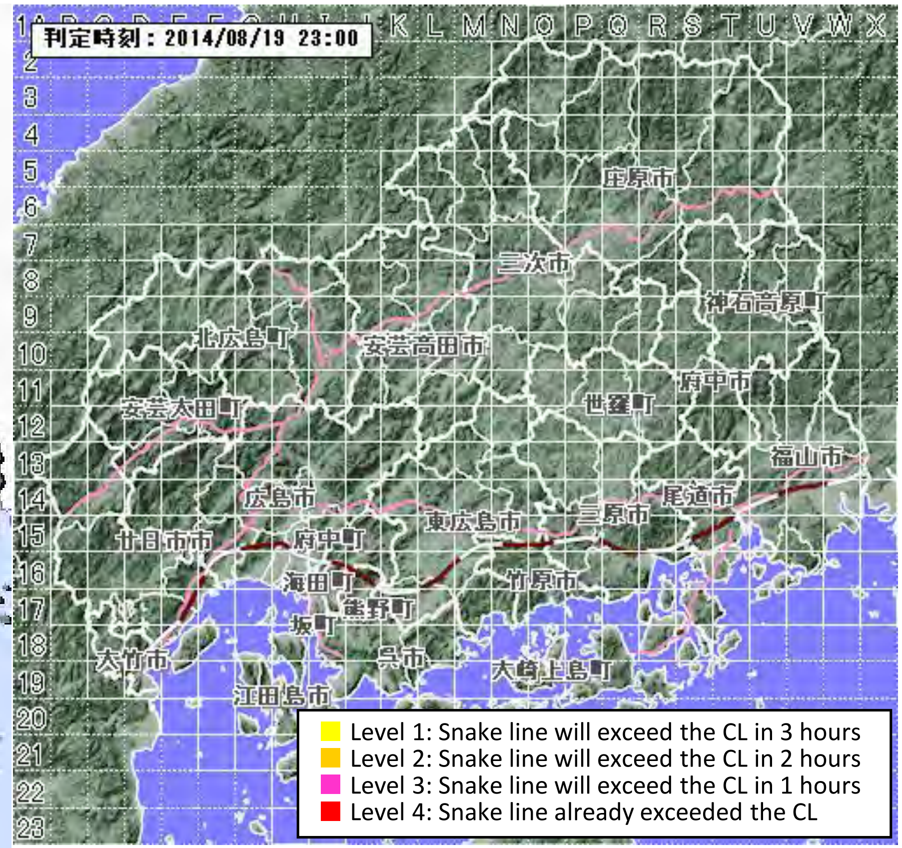
＜Damage Situation in Hiroshima＞

- Dead : 76
- Injured : 68
- Destroyed House (completely) : 179
- Destroyed House (partially) : 406
- Inundated Houses: 4,164
- Number of Sediment Disaster Events: 166 (107 debris flows, 59 slope failures)

2014/8/19 23:00

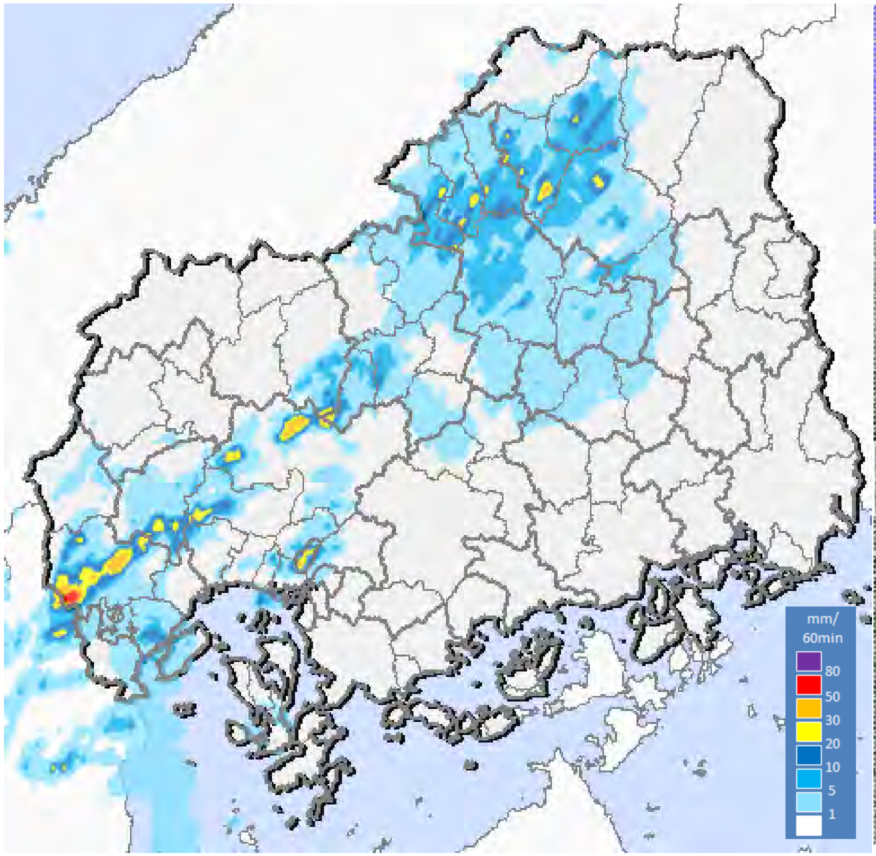


Rainfall Distribution

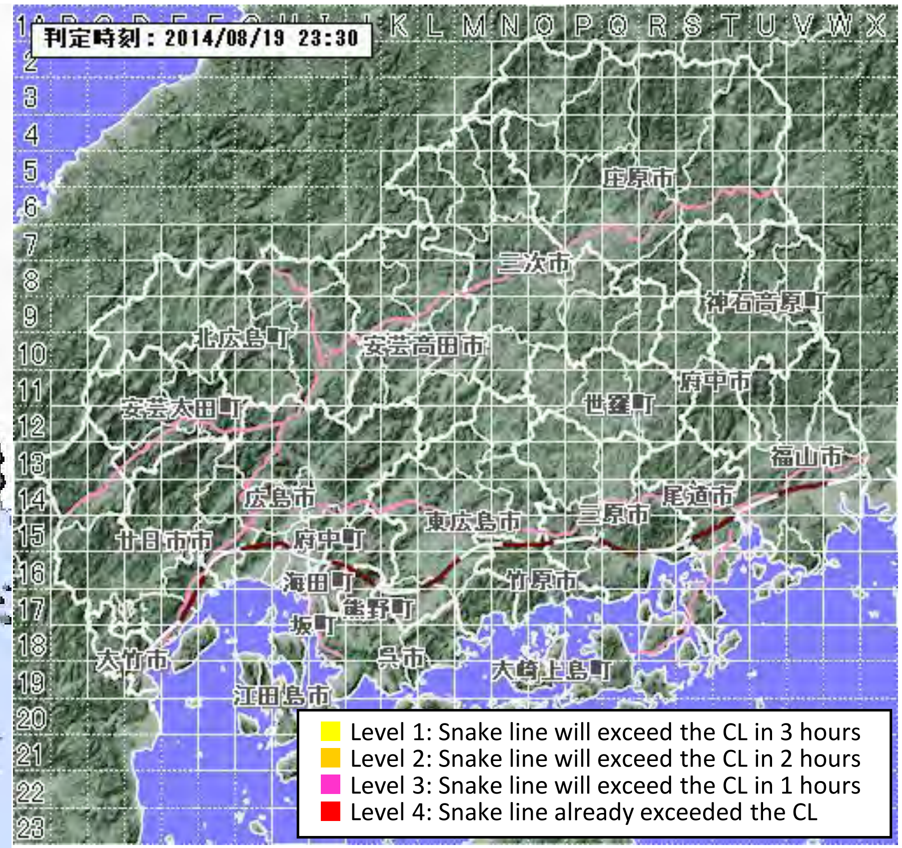


Risk Distribution

2014/8/19 23:30

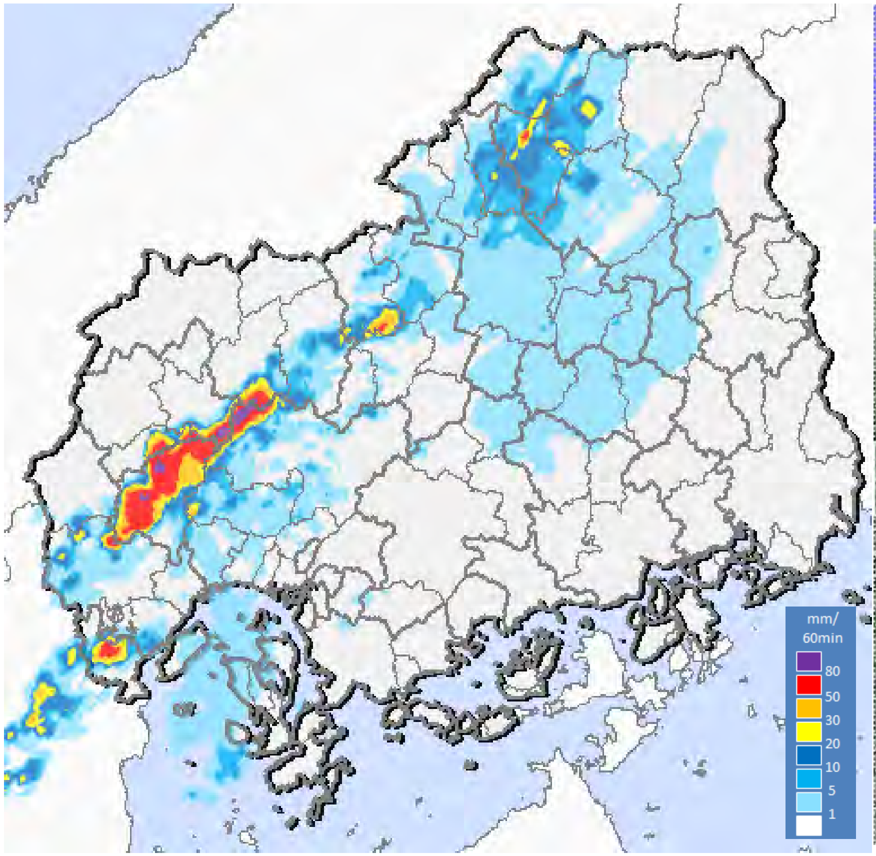


Rainfall Distribution

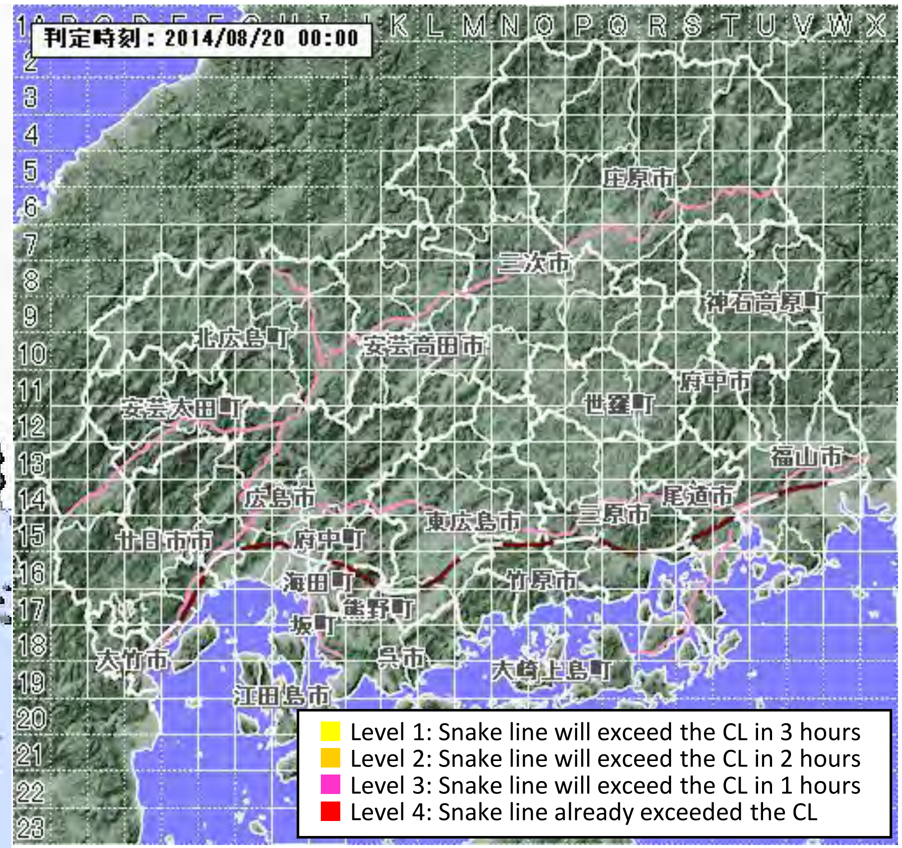


Risk Distribution

2014/8/20 00:00



Rainfall Distribution



Risk Distribution

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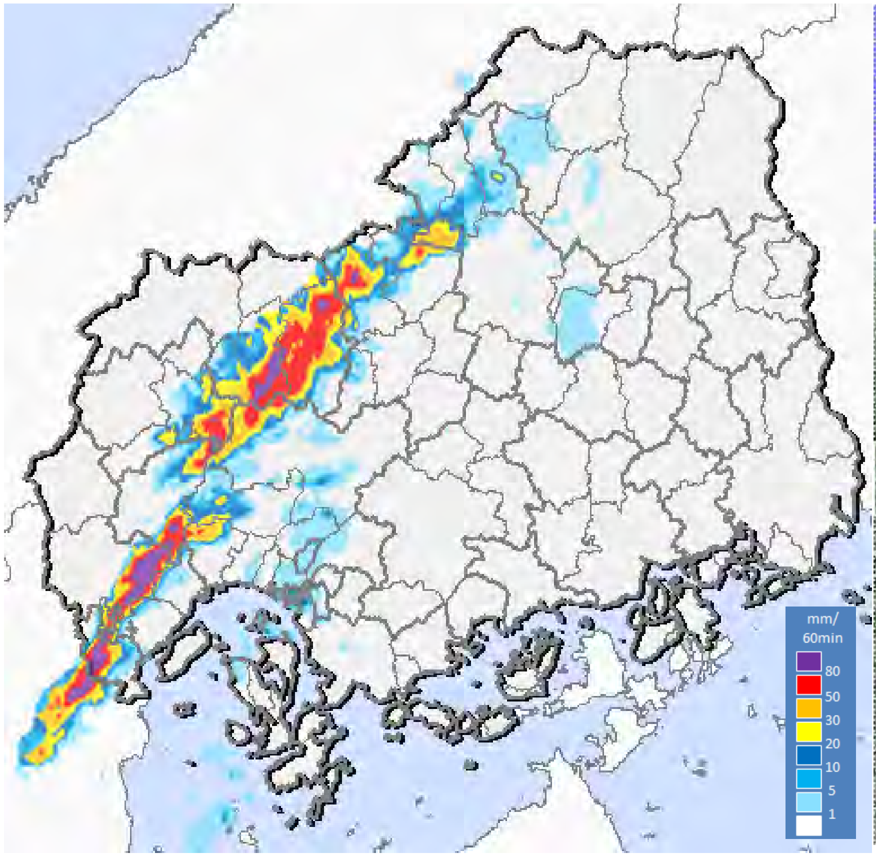
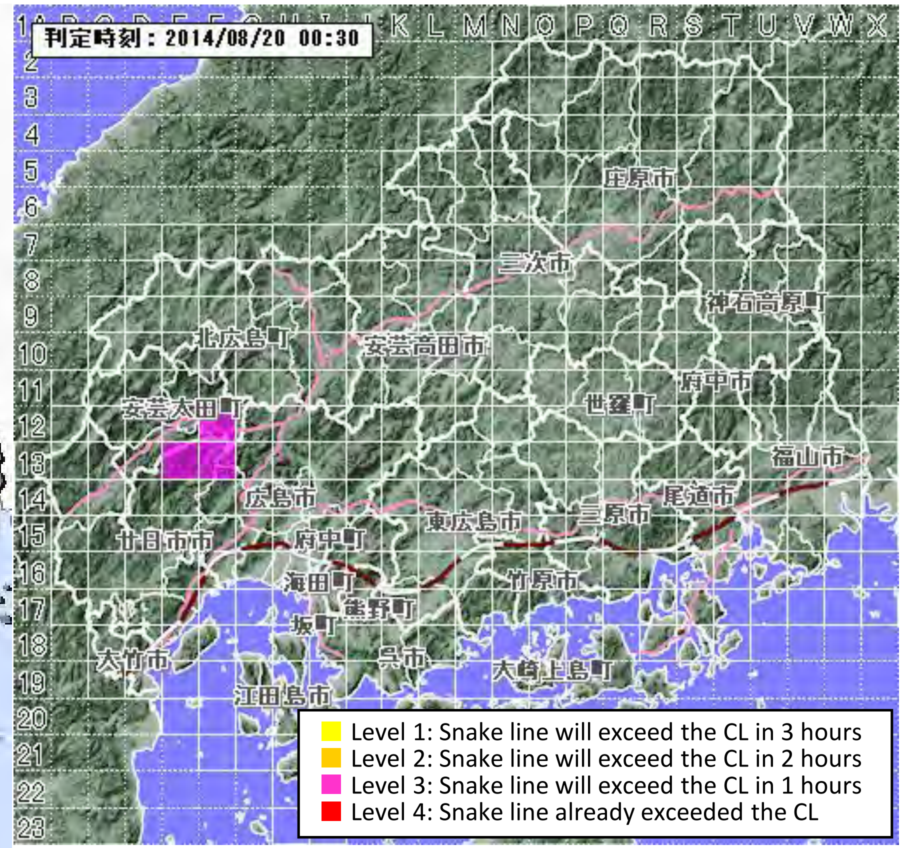


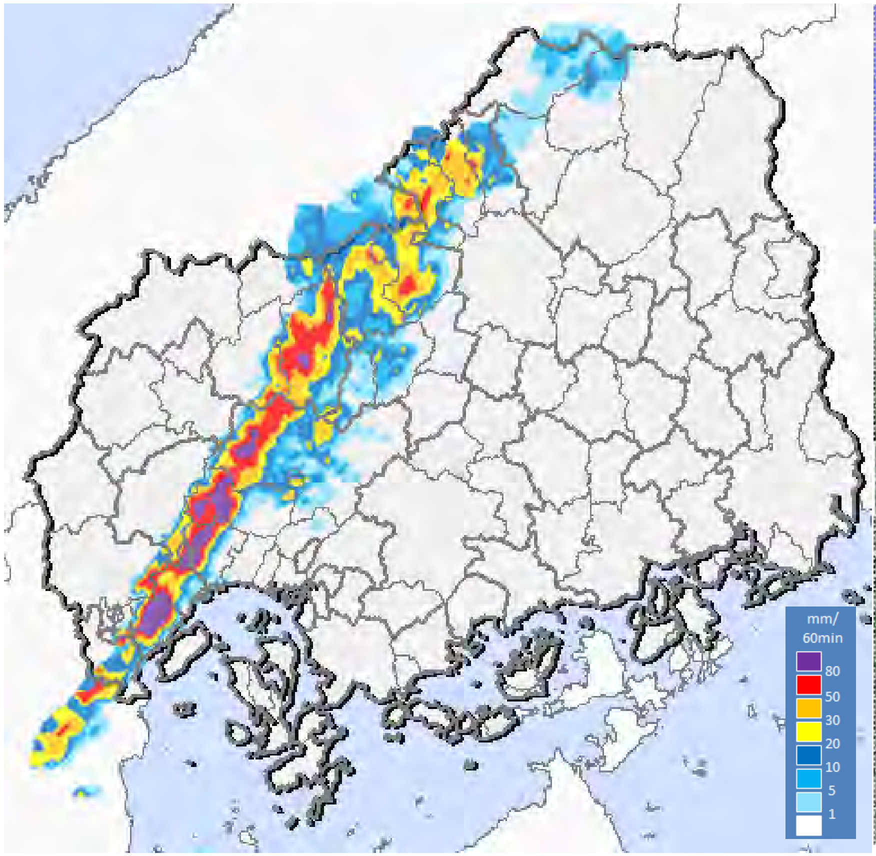
Rainfall Distribution



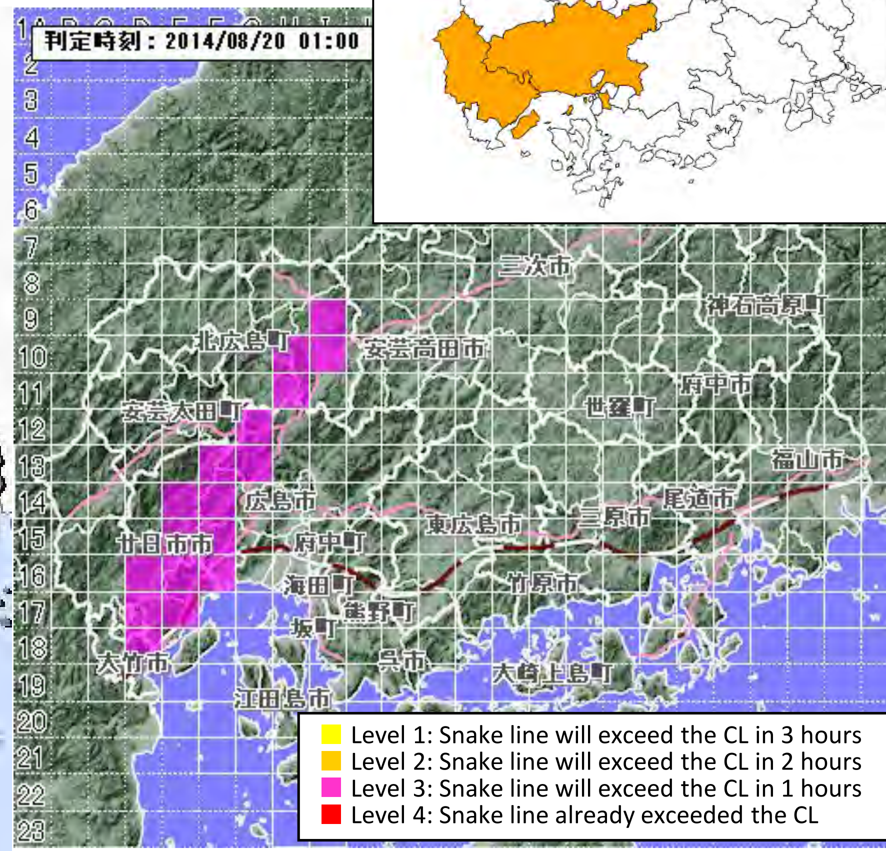
Risk Distribution

No.1 Early Warning Information
2014/8/20 01:15

2014/8/20 01:00

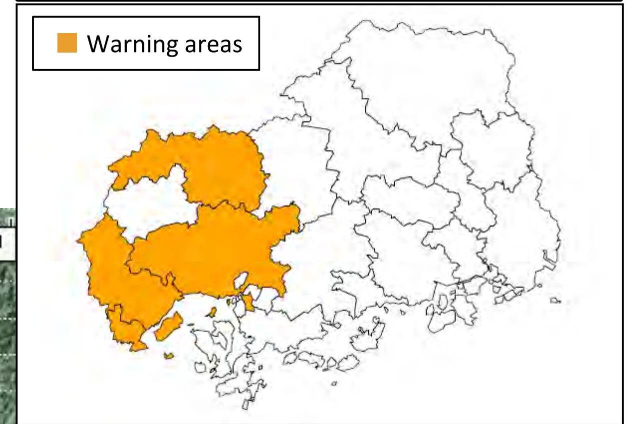


Rainfall Distribution

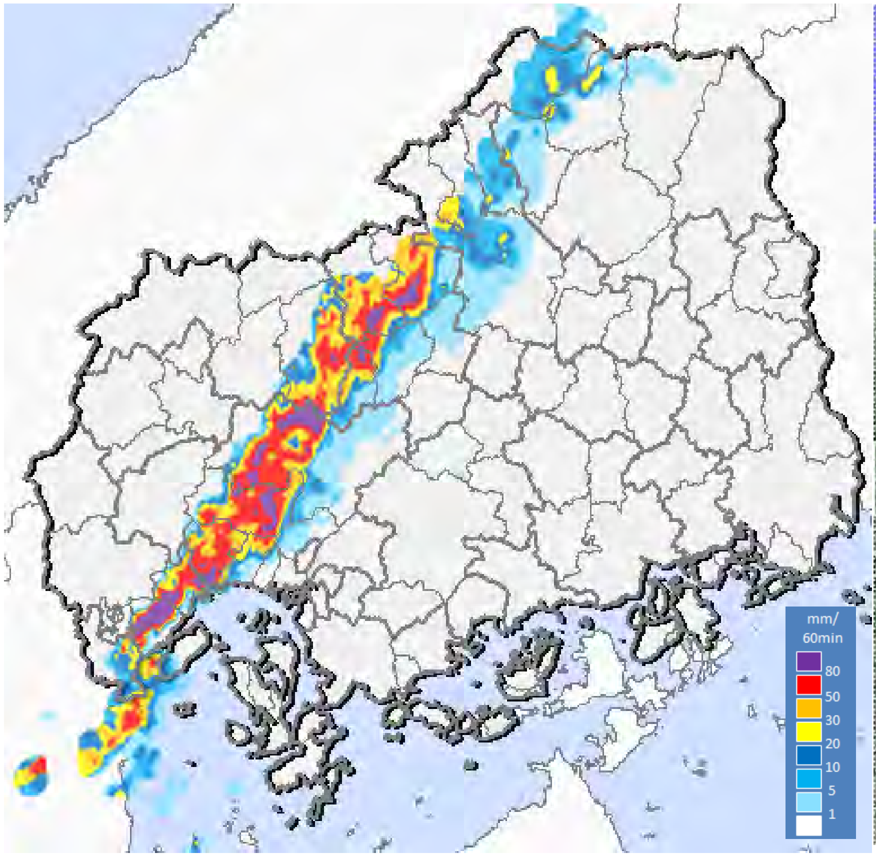


Risk Distribution

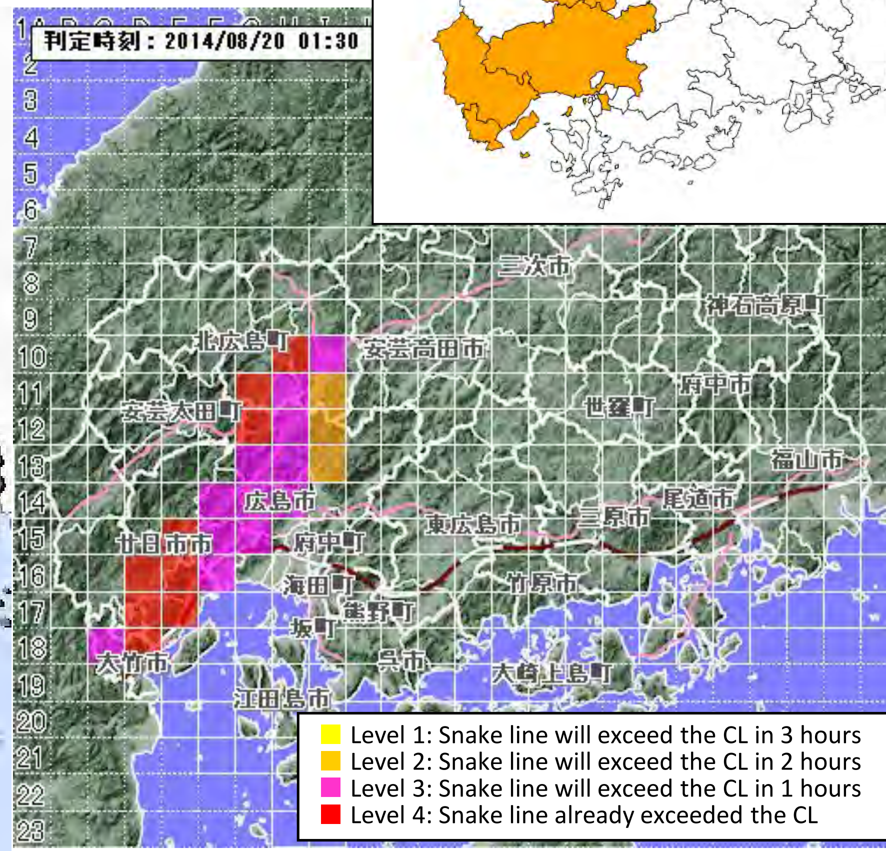
No.2 Early Warning Information
2014/8/20 01:35



2014/8/20 01:30

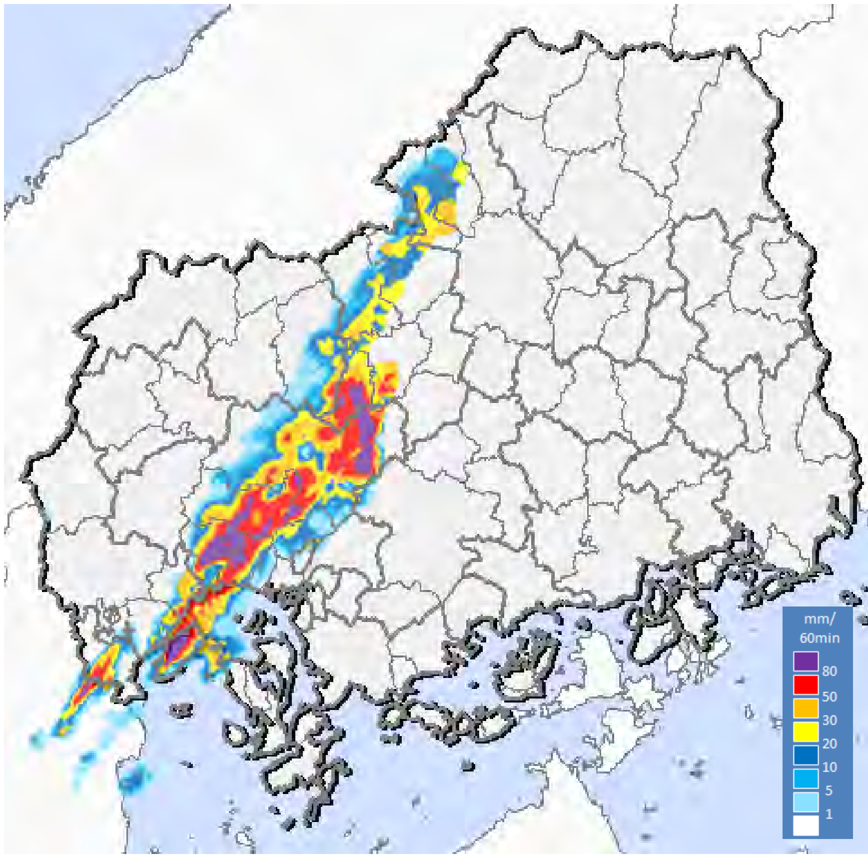


Rainfall Distribution

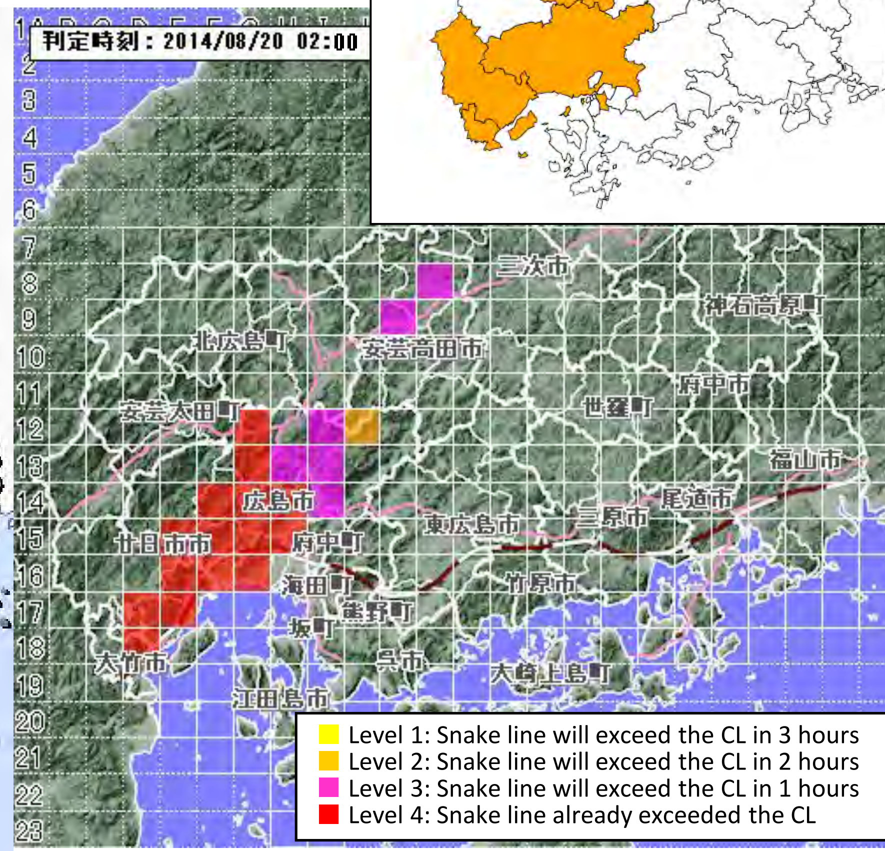


Risk Distribution

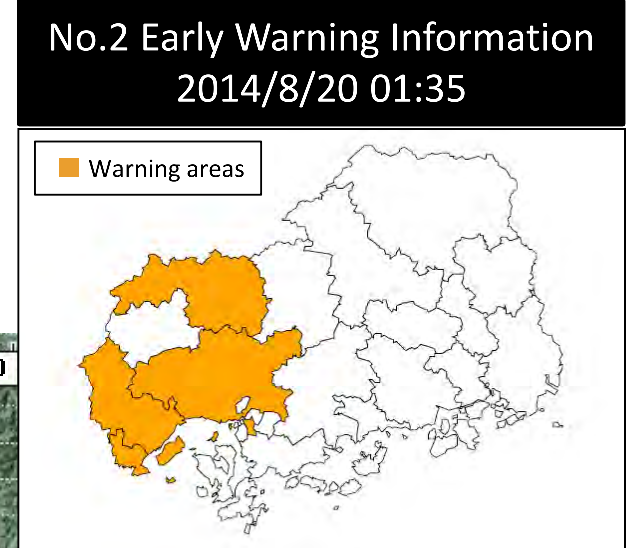
2014/8/20 02:00



Rainfall Distribution



Risk Distribution



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No.2 Early Warning Information
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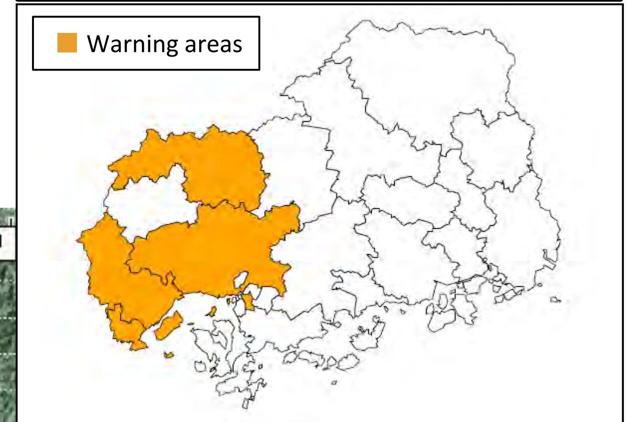
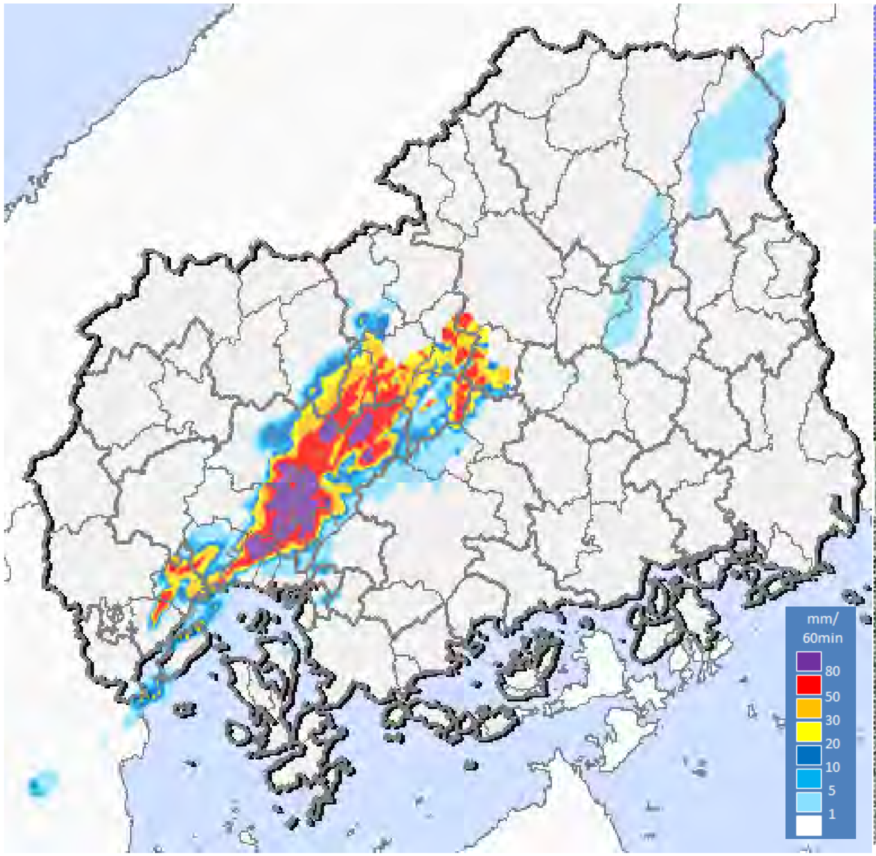
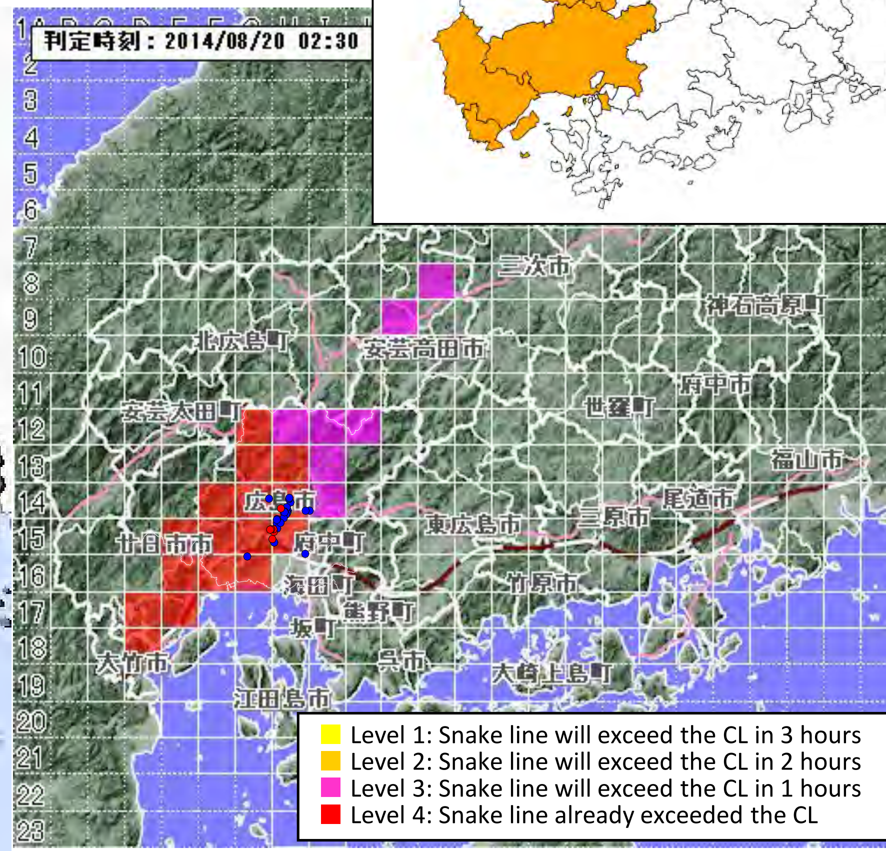


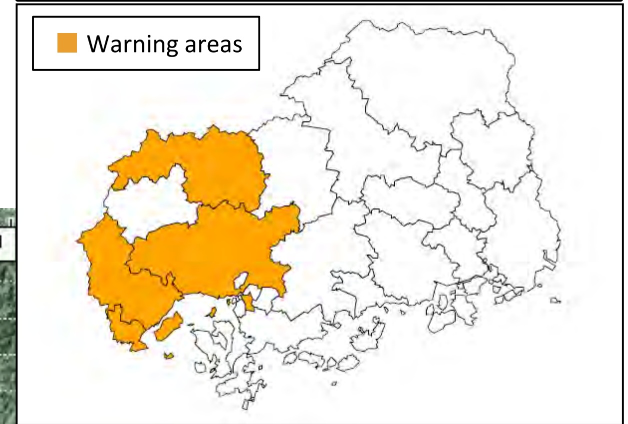


Rainfall Distribution

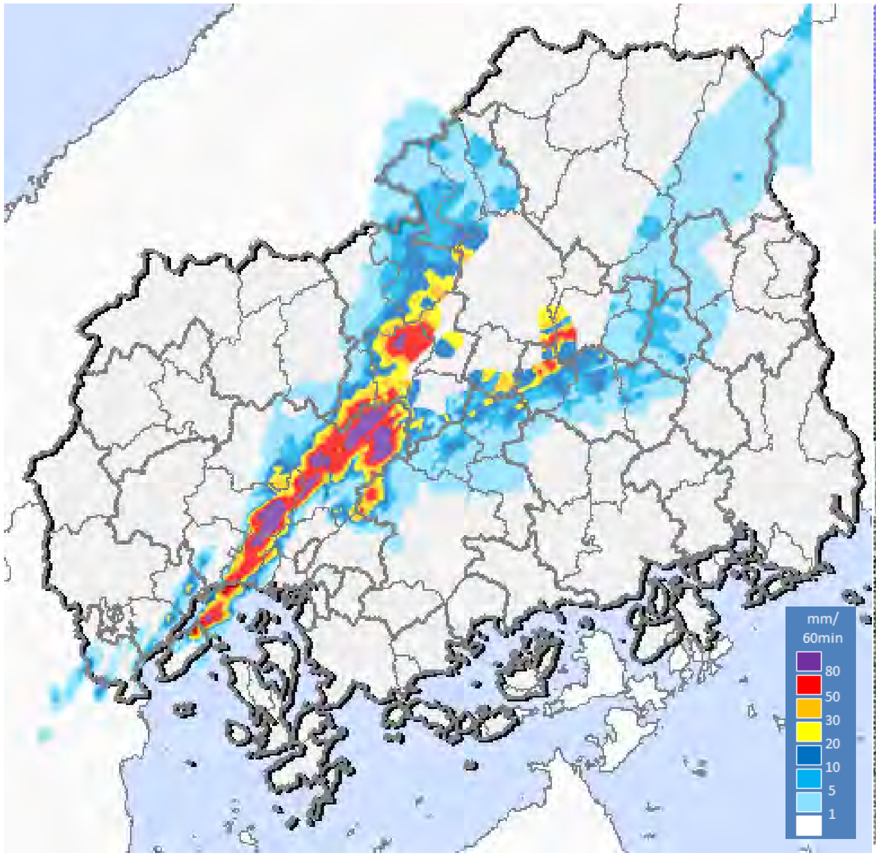


Risk Distribution

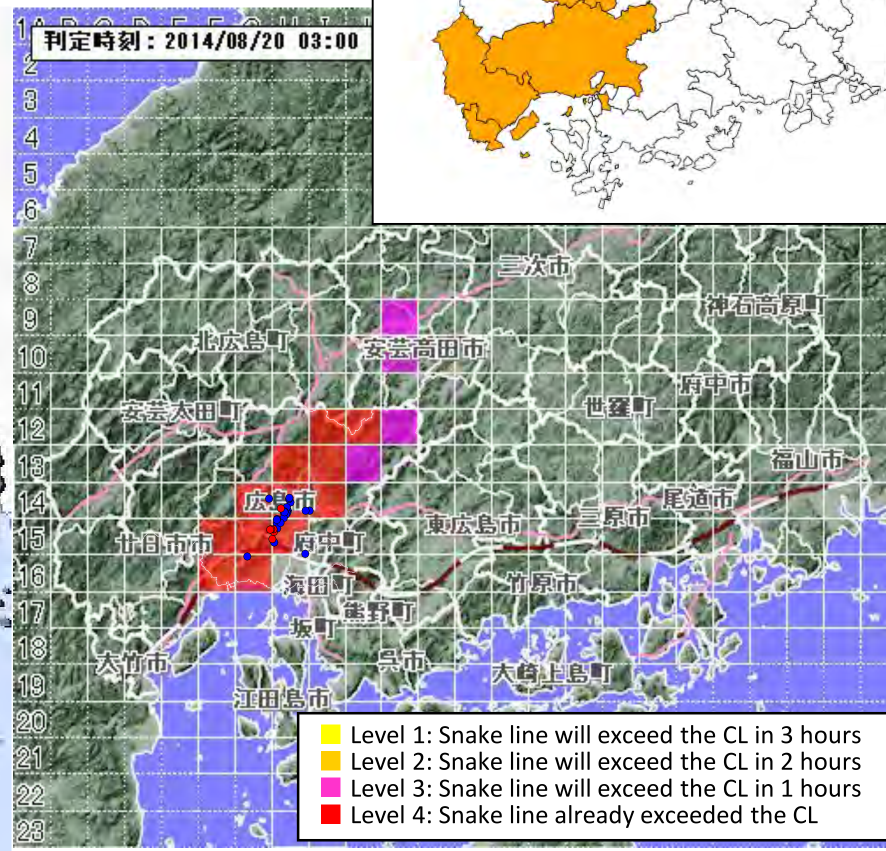
No.2 Early Warning Information
2014/8/20 01:35



2014/8/20 03:00



Rainfall Distribution



Risk Distribution

No.3 Early Warning Information
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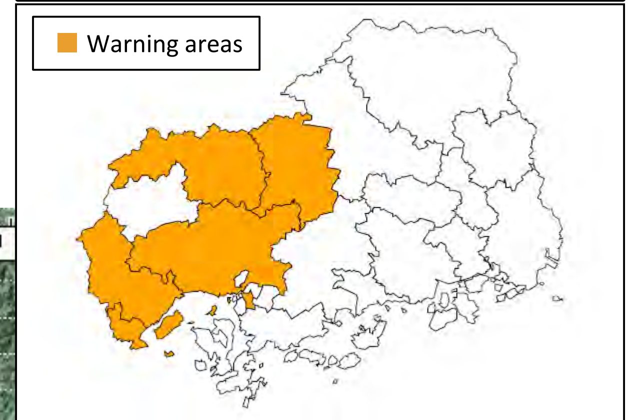

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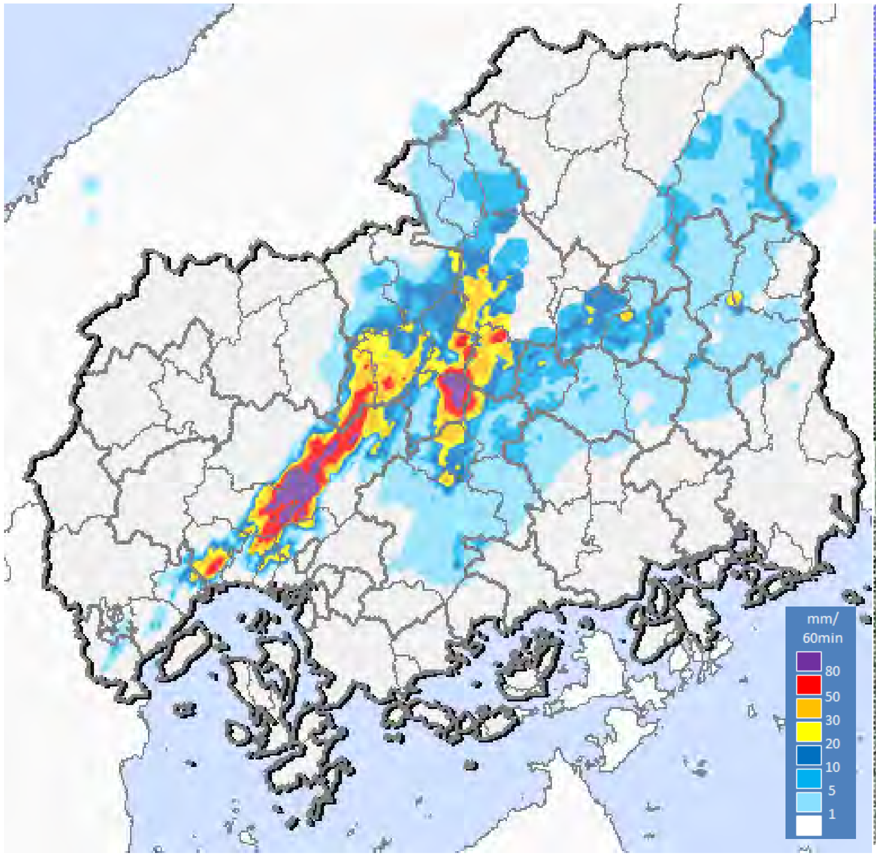
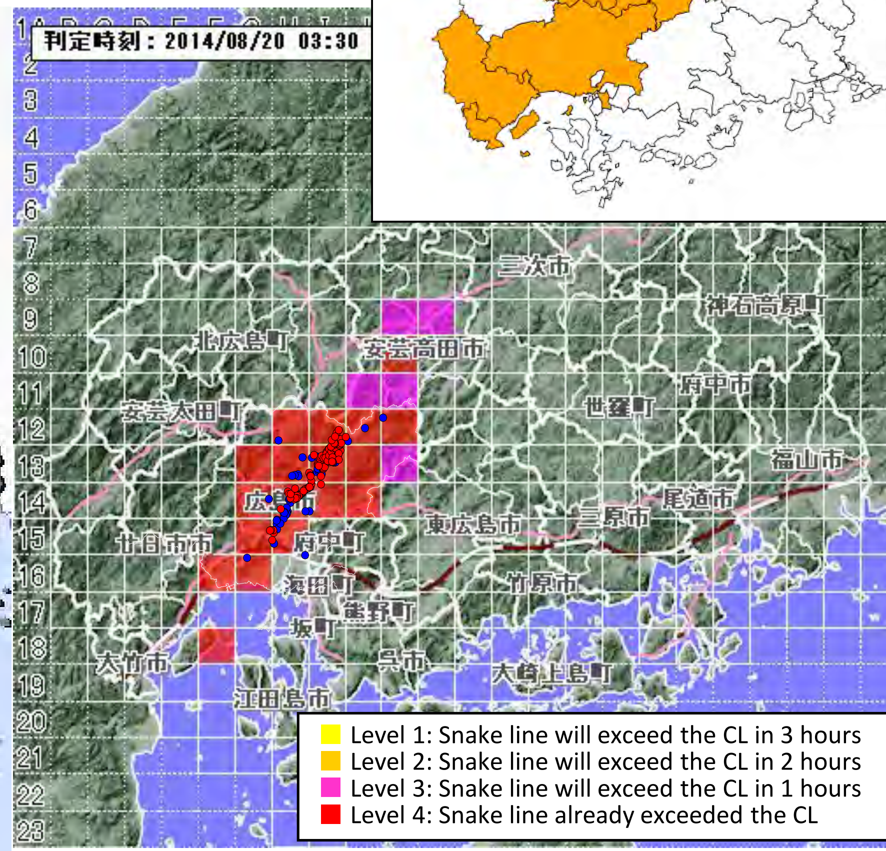


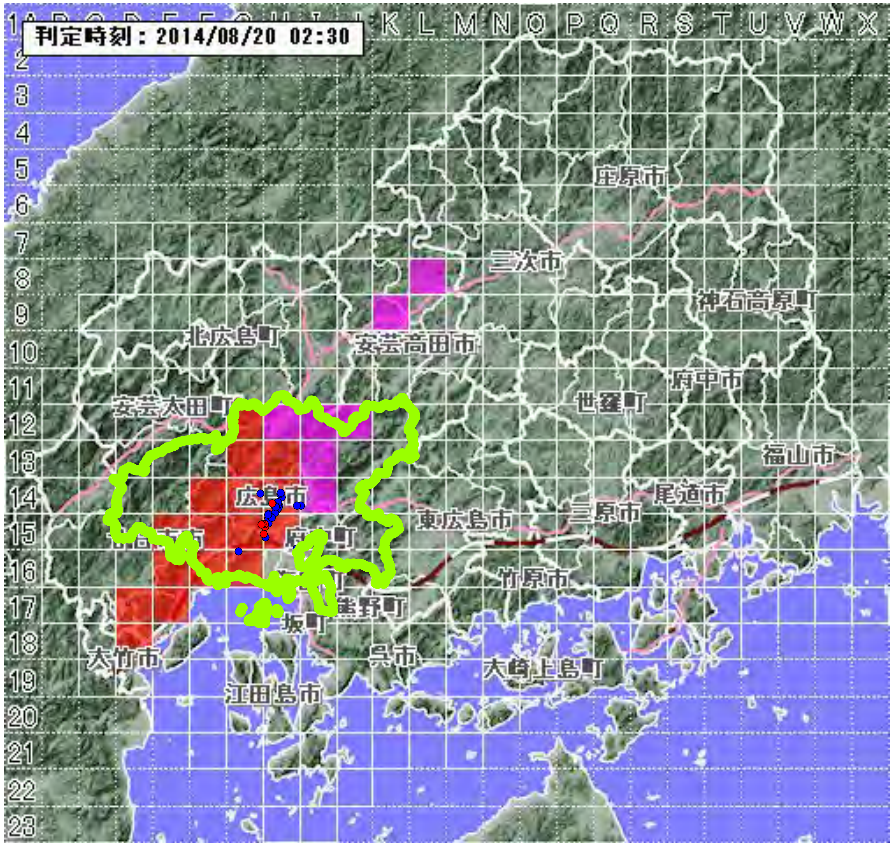
Rainfall Distribution



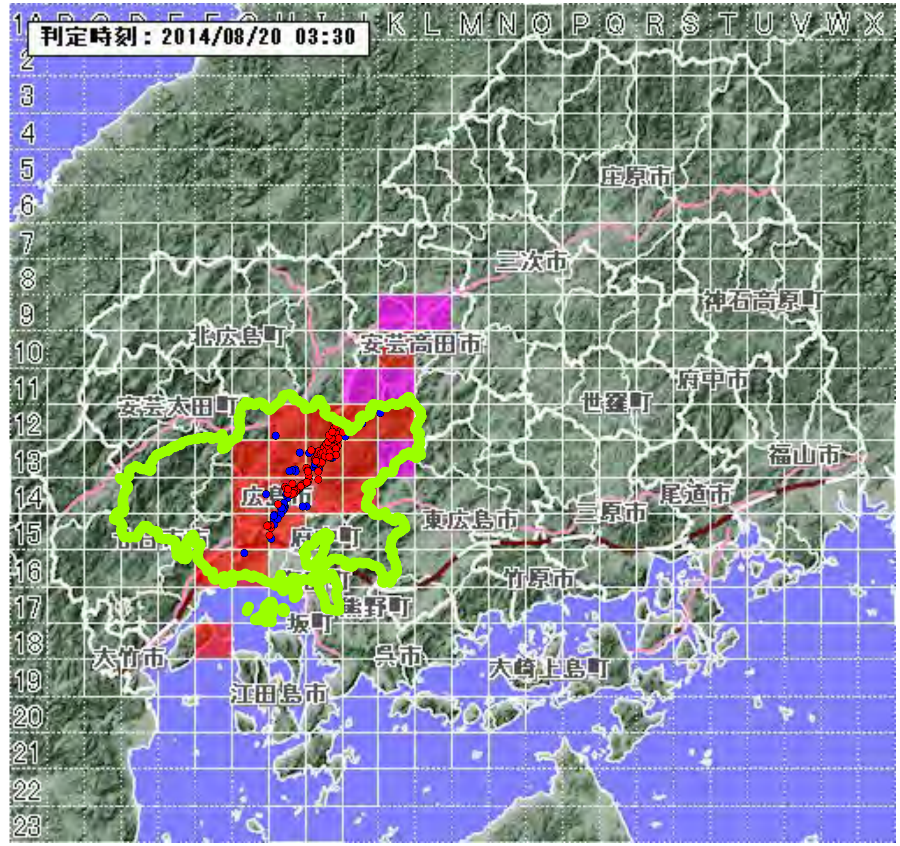
Risk Distribution

Disaster distribution

2014/8/20 2:30



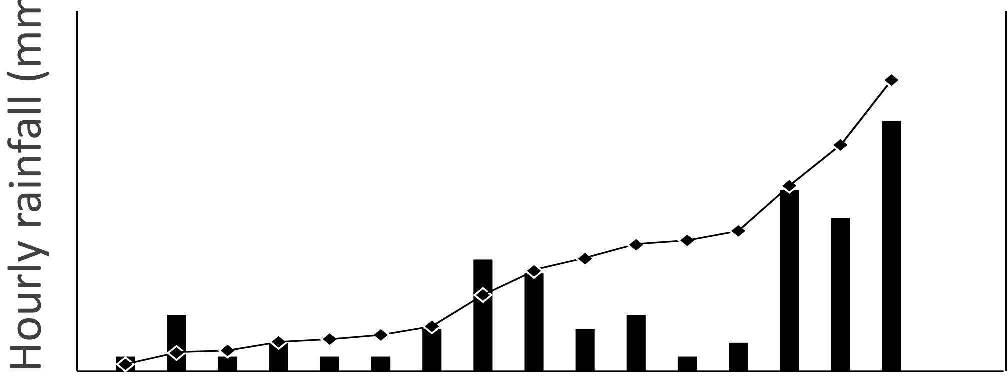
2014/8/20 3:30



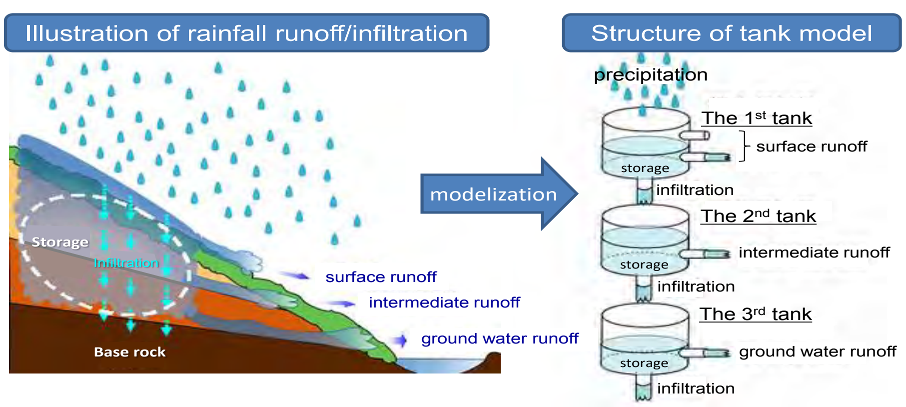
The risk distribution corresponded with the disaster points.

Methodology

Hourly Rainfall

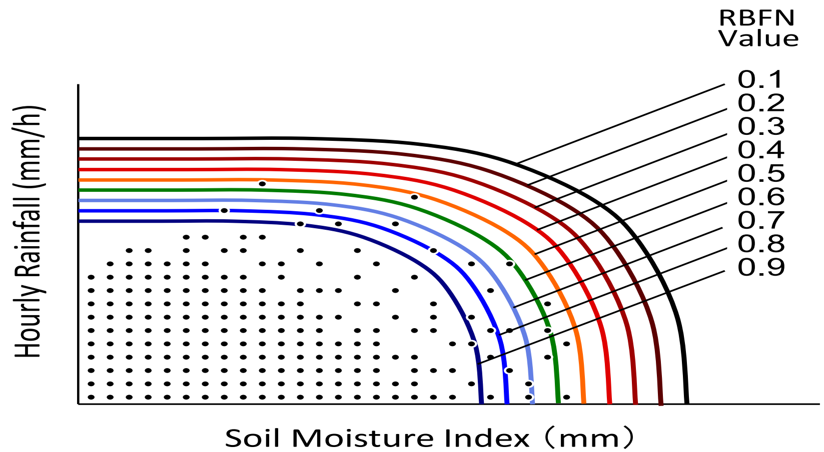


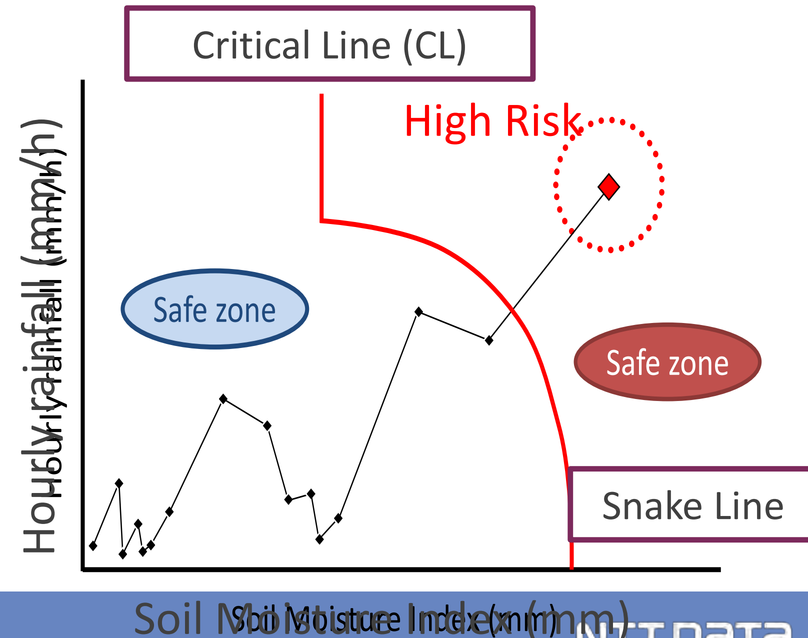
Soil Moisture Index (estimated from tank model)



SMI is the total water depth of the three tanks.

Risk Level based on Critical Lines

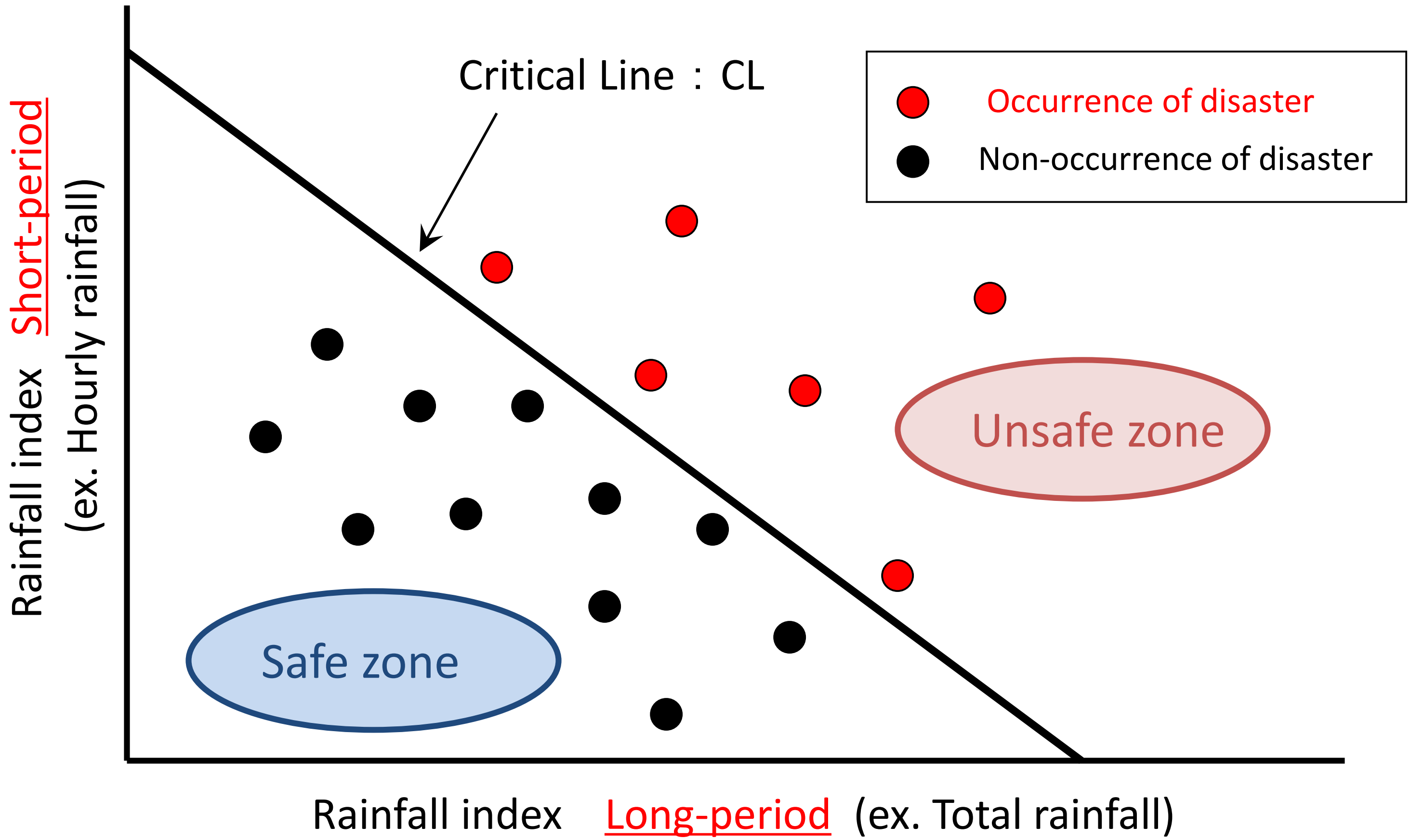




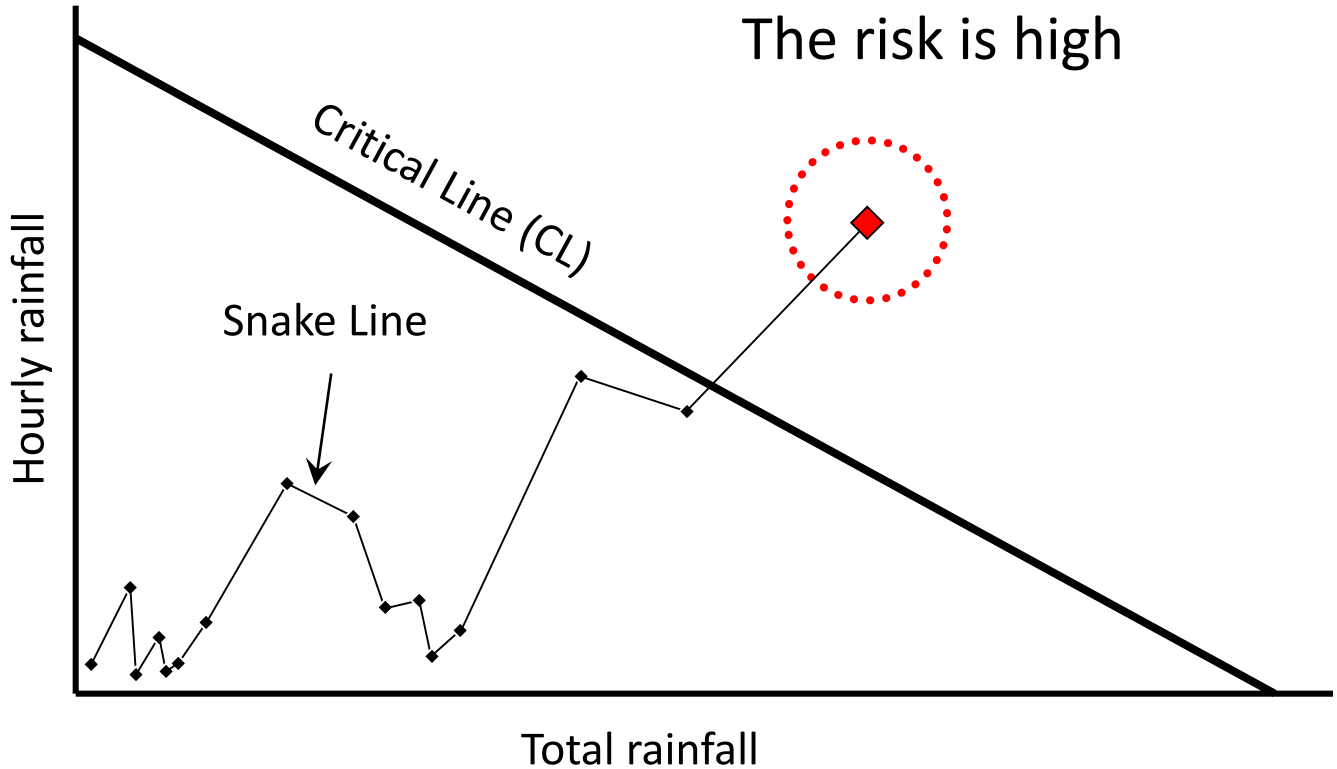
Landslide disaster forecasting:

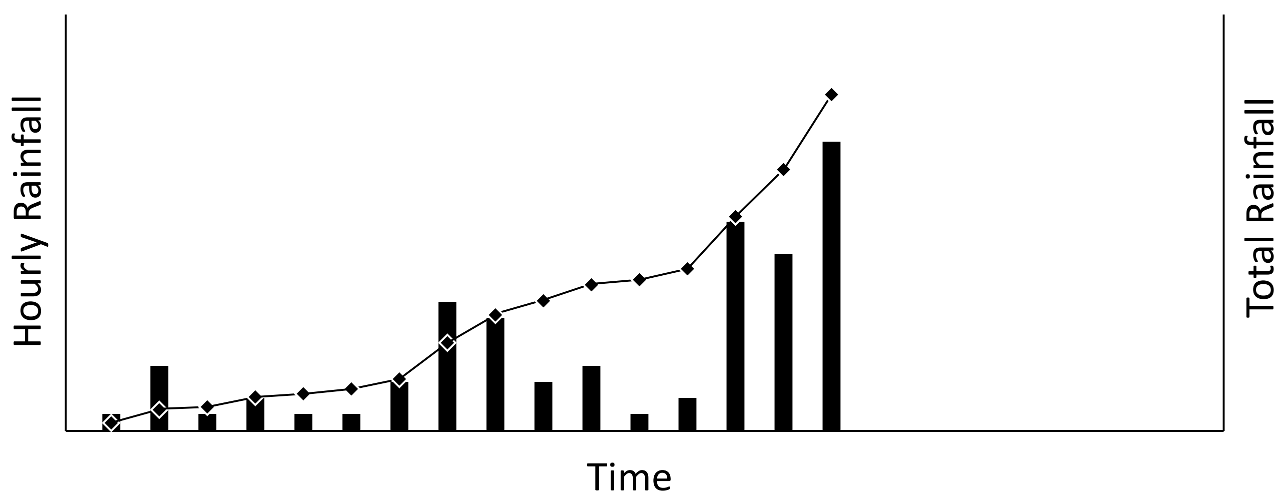
Landslide disaster forecasting is the most important component of the early warning system.

The main methodology of forecasting is to set a criterion for occurrences of landslide disaster based on 2 rainfall indices in Japan.

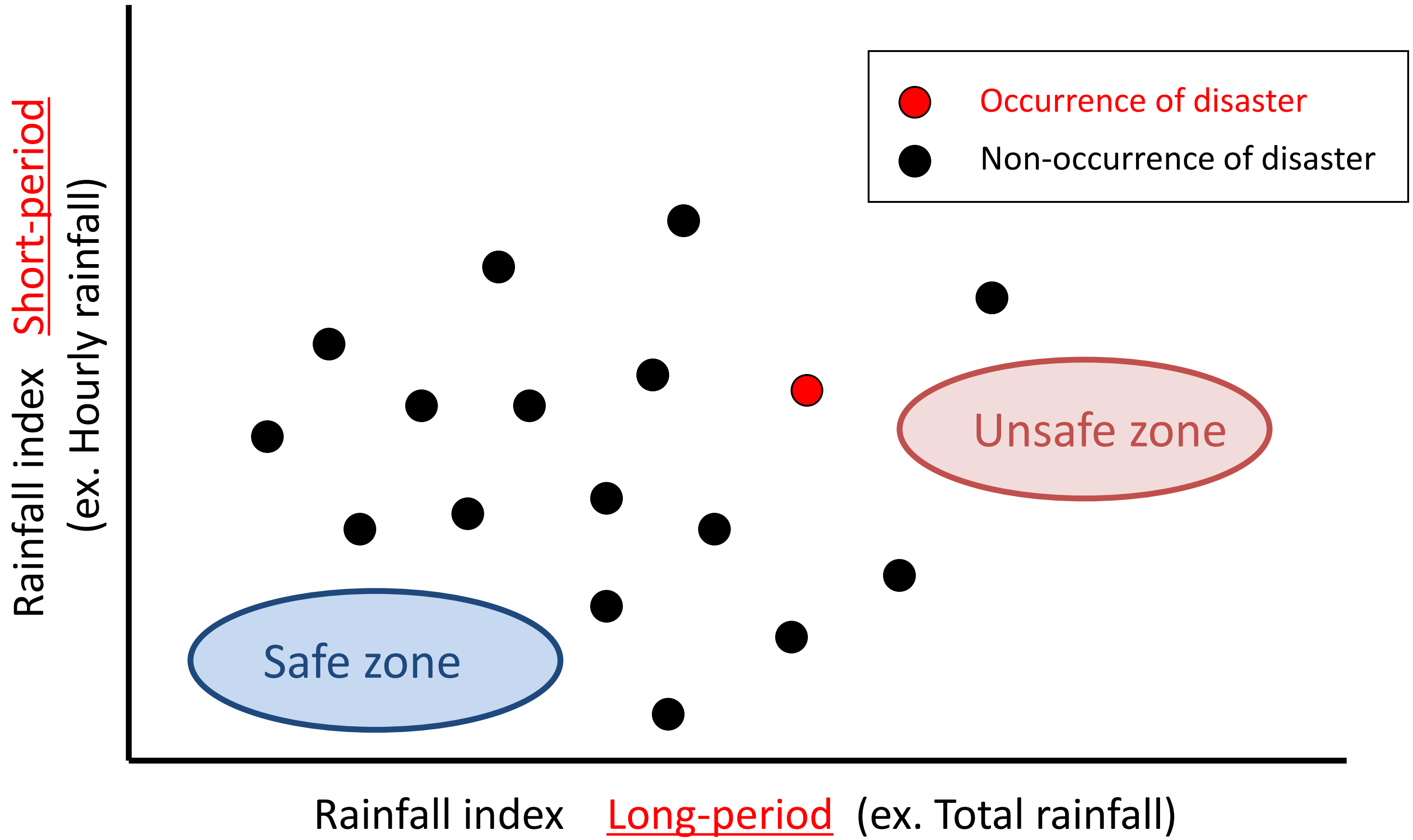


How can we evaluate the risk using the CL?





Demerits of the conventional methodology



- We can’t define the CL without enough disaster data.
- We have to define the CL based on a subjective approach.

In order to solve some of the problems of the conventional CL, we proposed the methodology for defining the new CL using RBF Network.

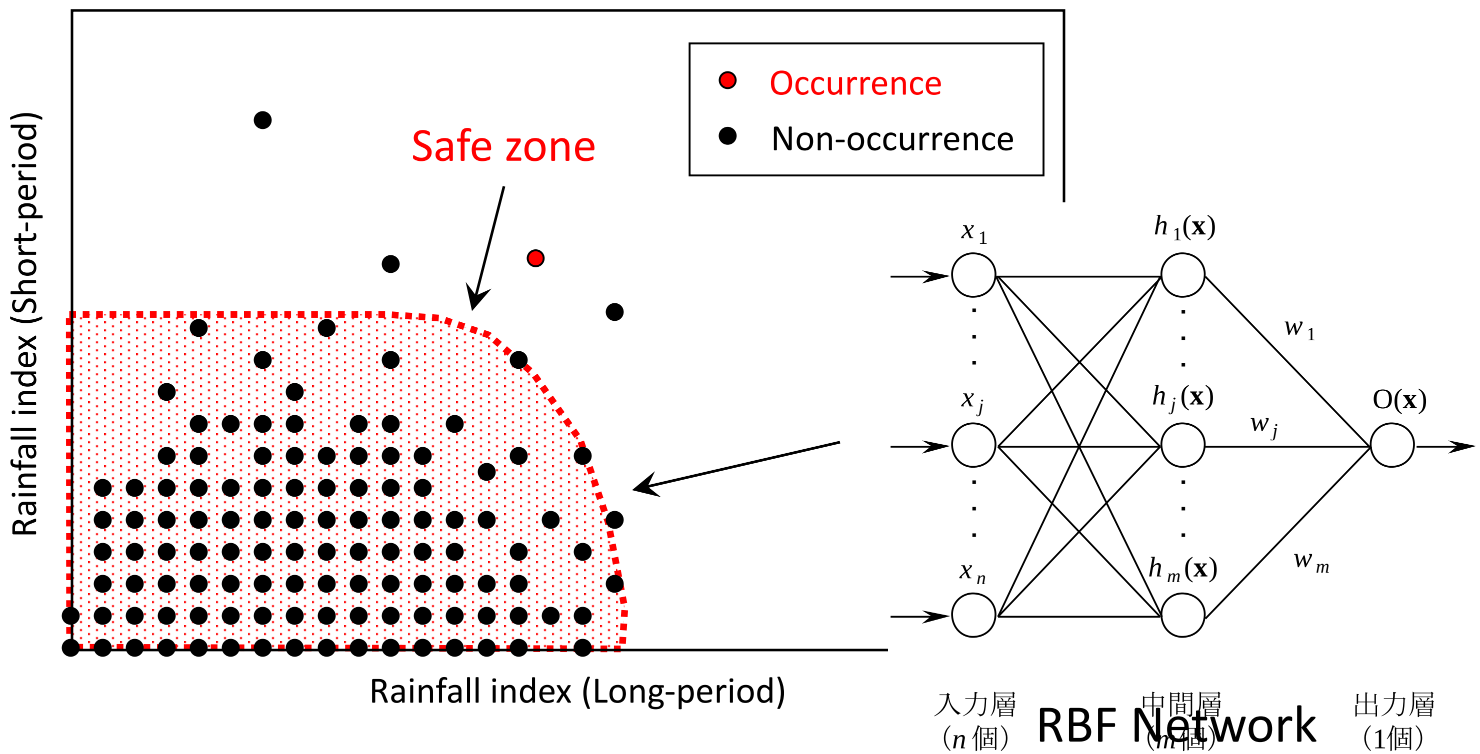
Concepts for defining the new CL

To be able to define the CL without disaster data and objectively

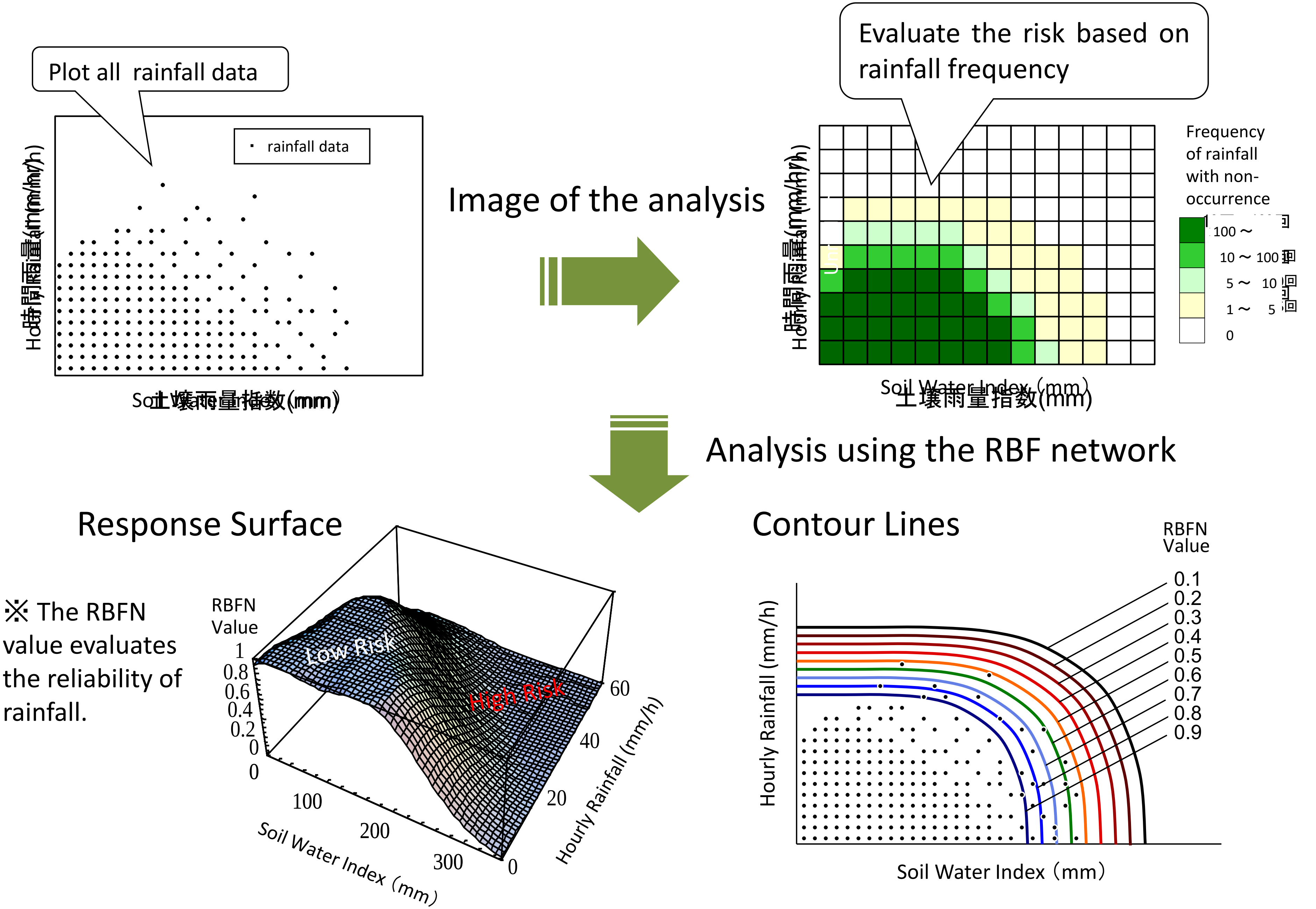
⇒ We define the safe zone using non-occurrence data.

(The occurrence data is not necessary.)

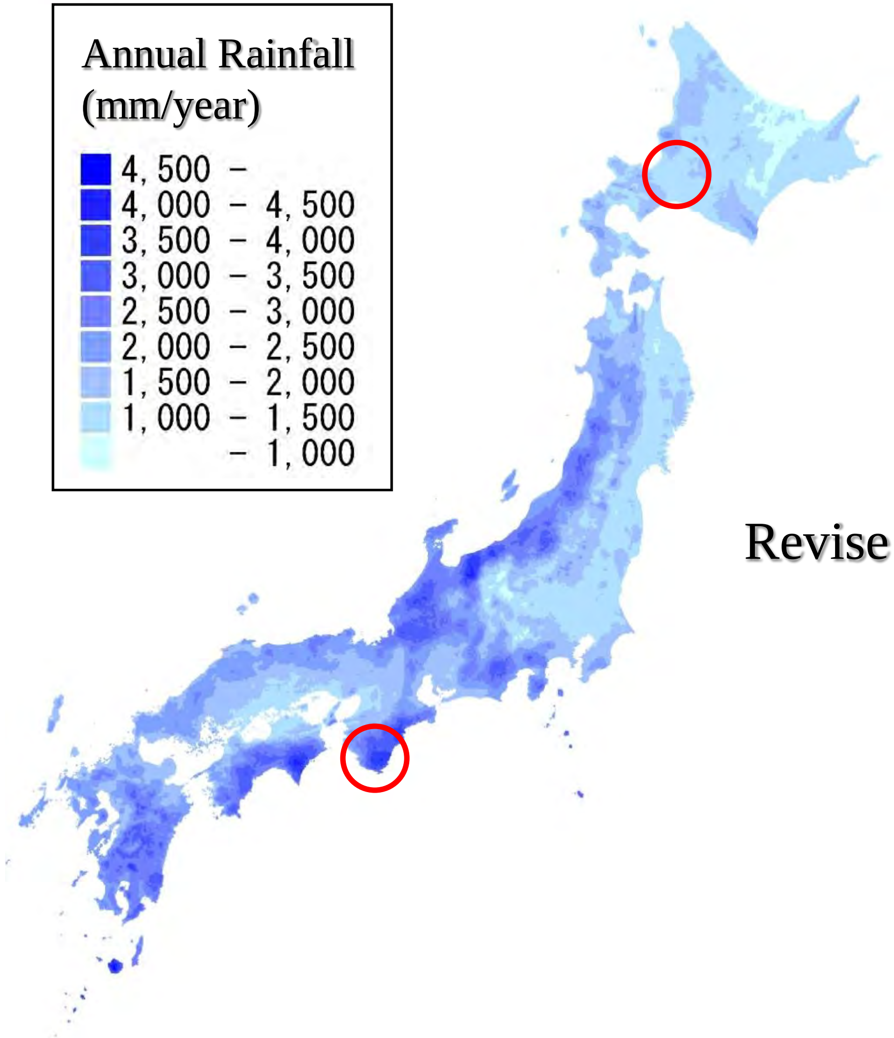
⇒ We use the RBF Network as an objective approach.



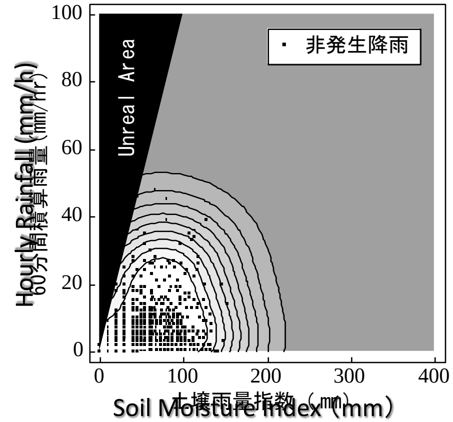
The methodology for defining the CL using the RBF network:



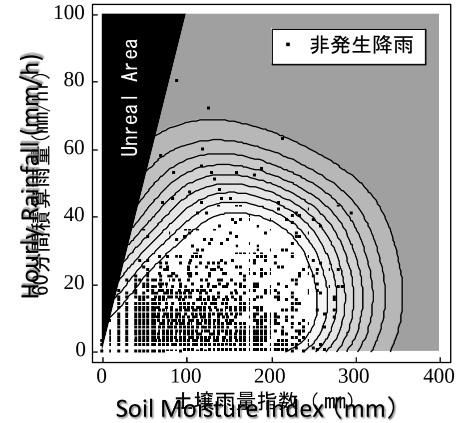
Example of the CL:



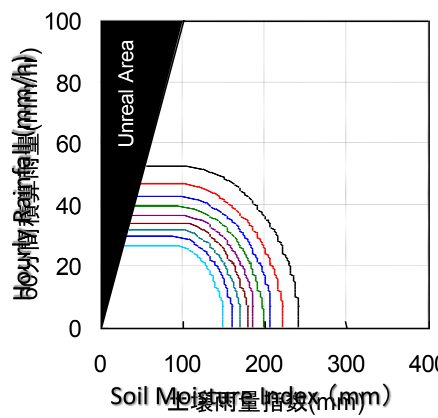
Annual Rainfall about 1,500mm/y

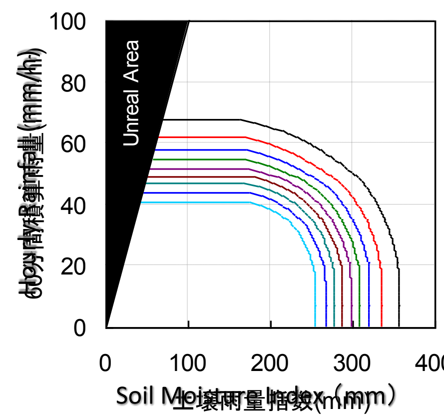


Annual Rainfall about 4,500mm/y



Revise the Contour Lines

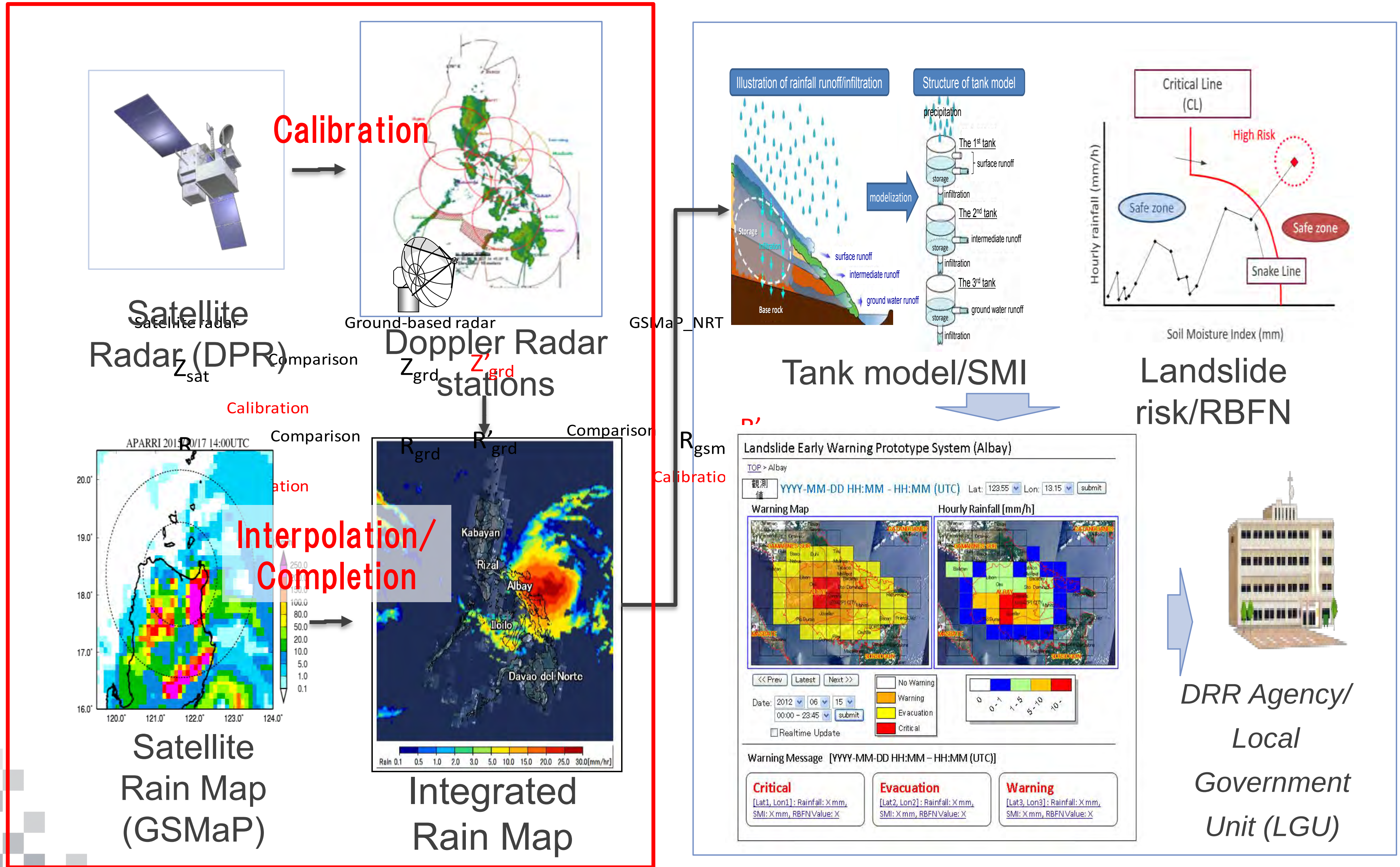




The methodology can reflect these characteristics onto the surface objectively and easily.

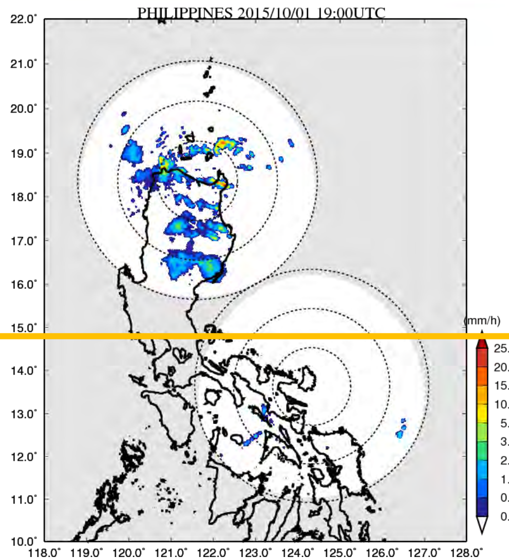
Hybrid rainfall monitoring using ground radar and satellite sensors

Hybrid rainfall monitoring for real-time landslide warning

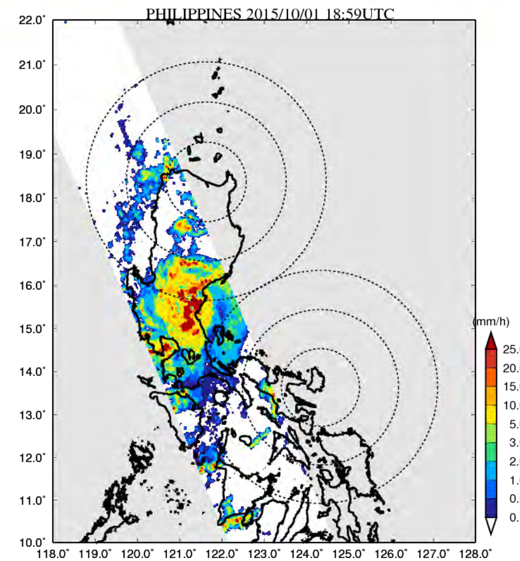


Radar composite

Ground radar

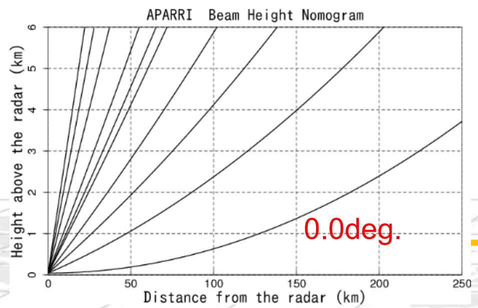


DPR



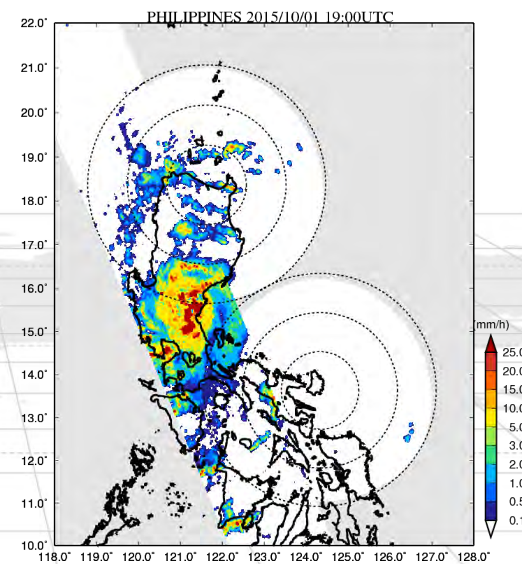
Ground radar calibrated by the DPR

Ground radar beam height



Weighting function

Radar composite

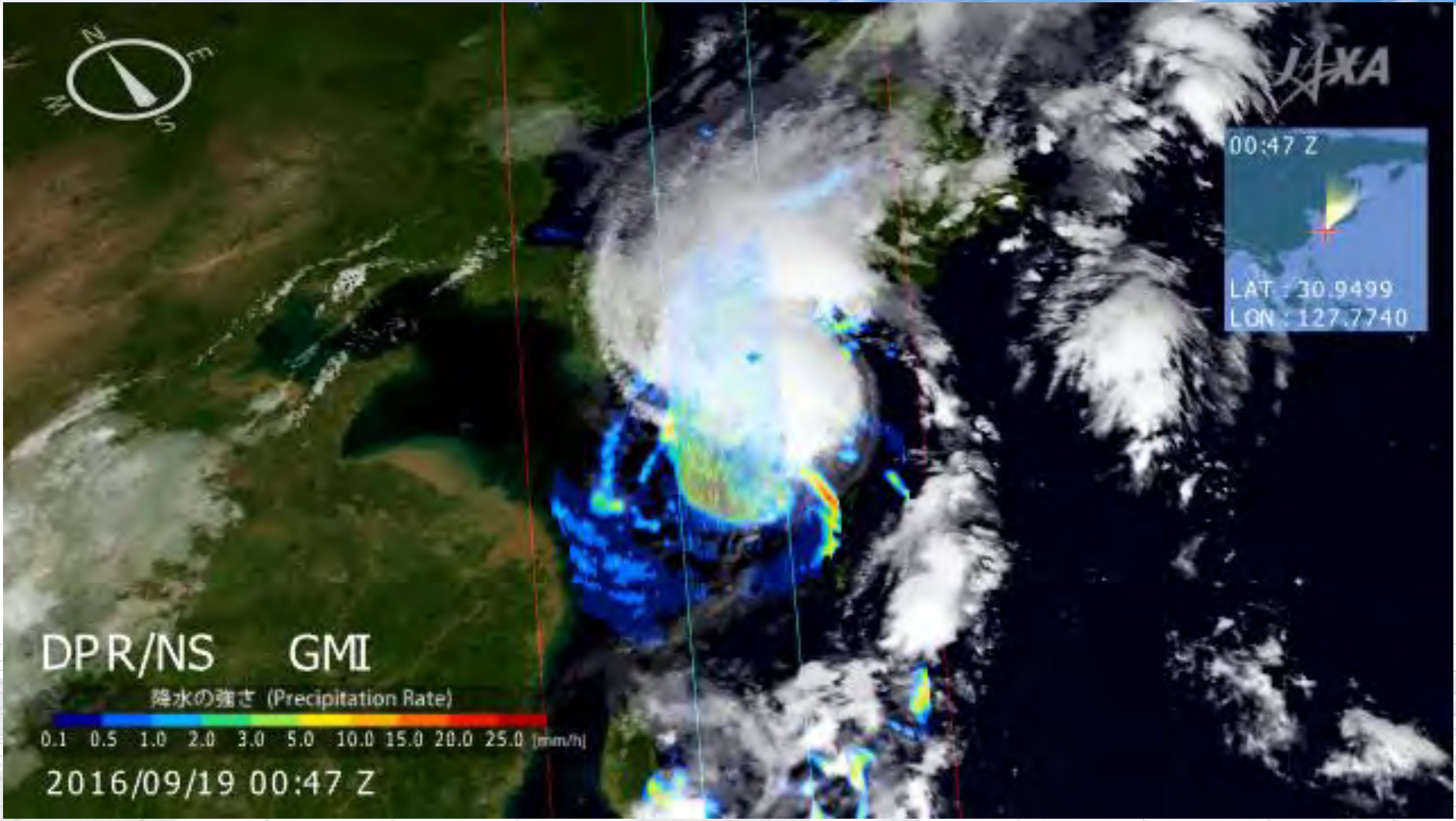


$$G_j = \frac{1}{H_j}\left\{ \frac{1}{H_{rad,j}} \frac{\sum_{i=1}^{N} D_i W_i}{\sum_{i=1}^{N} W_i} + \frac{1}{H_{sat}} D_{sat,j} \right\}$$

Ground Radar *DPR*

Here, the ground radar beam height was used as a weighting function in merging the ground radar and the DPR.

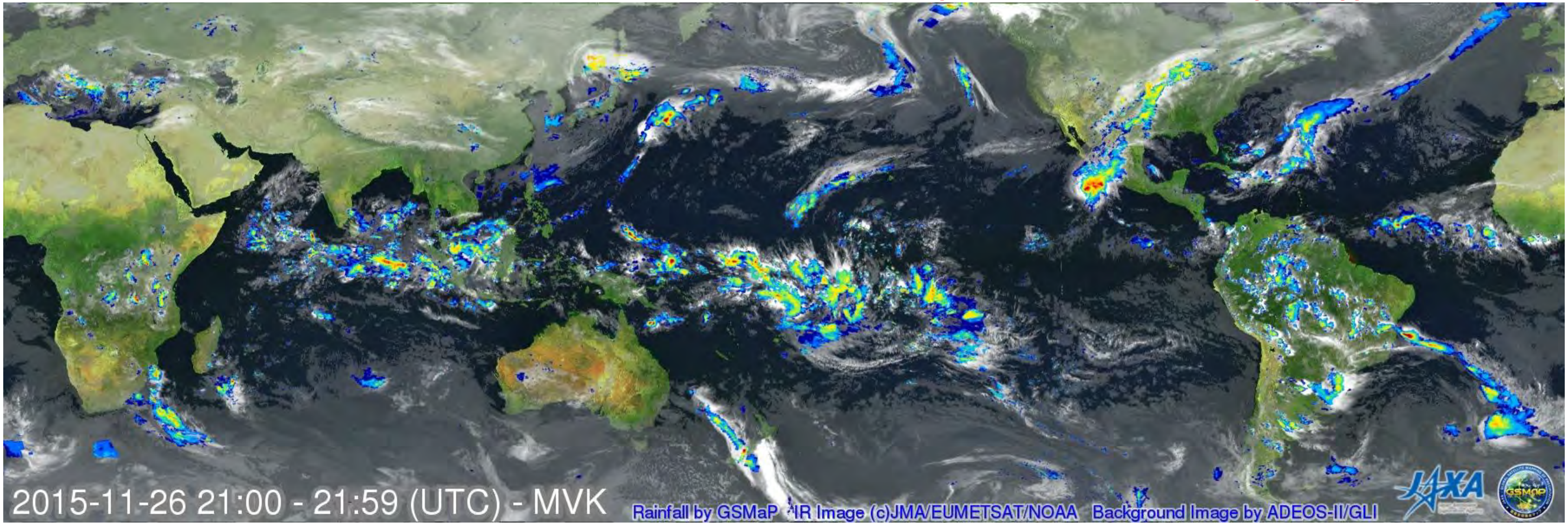
Example of DPR observation data

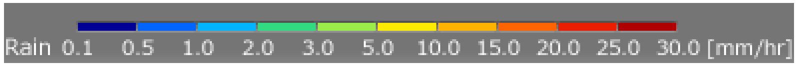


Global Satellite Mapping of Precipitation (GSMaP)

GSMaP observed Hurricane SANDRA (Category 7) at 21Z Nov.26, 2015

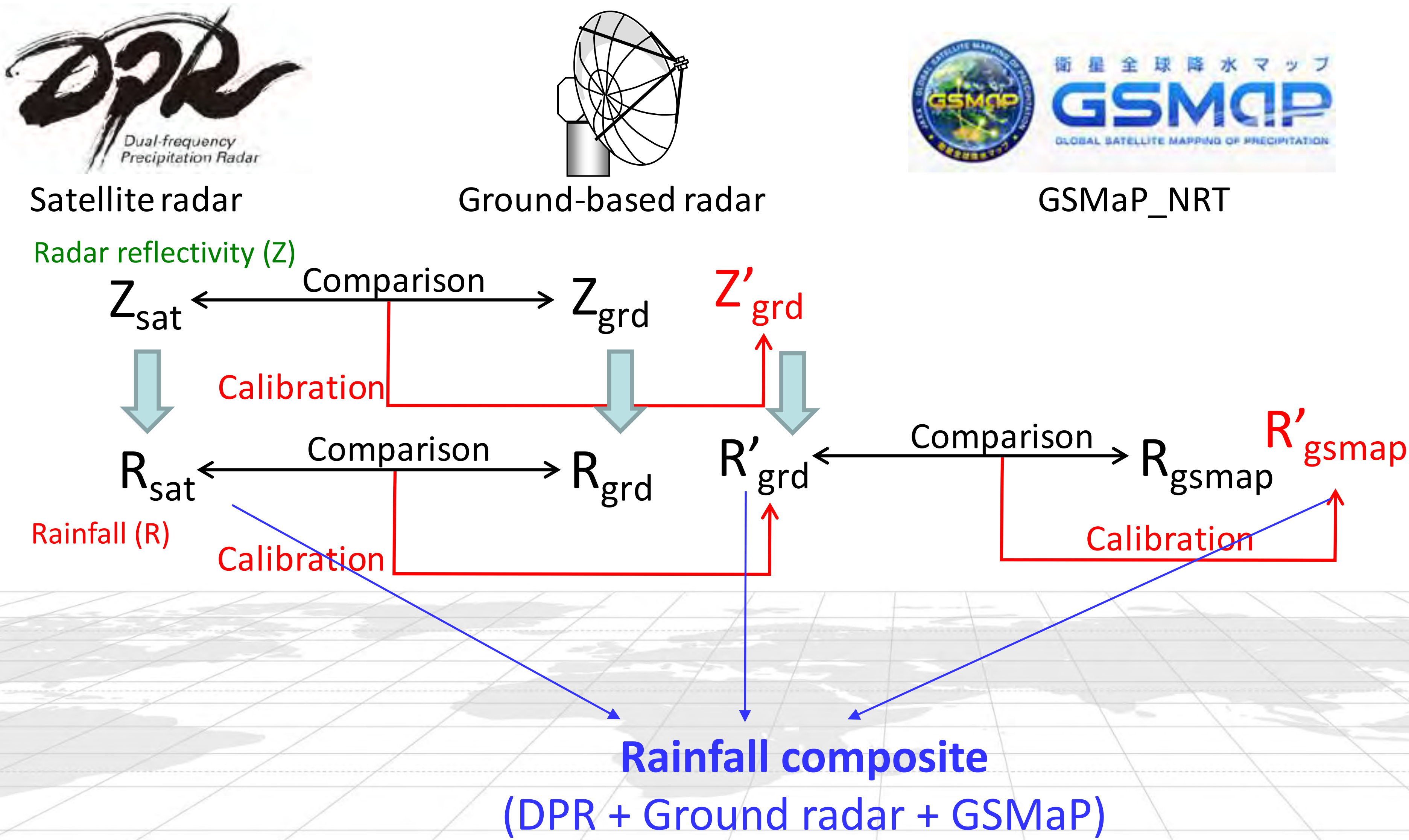
http://sharaku.eorc.jaxa.jp/GSMaP/





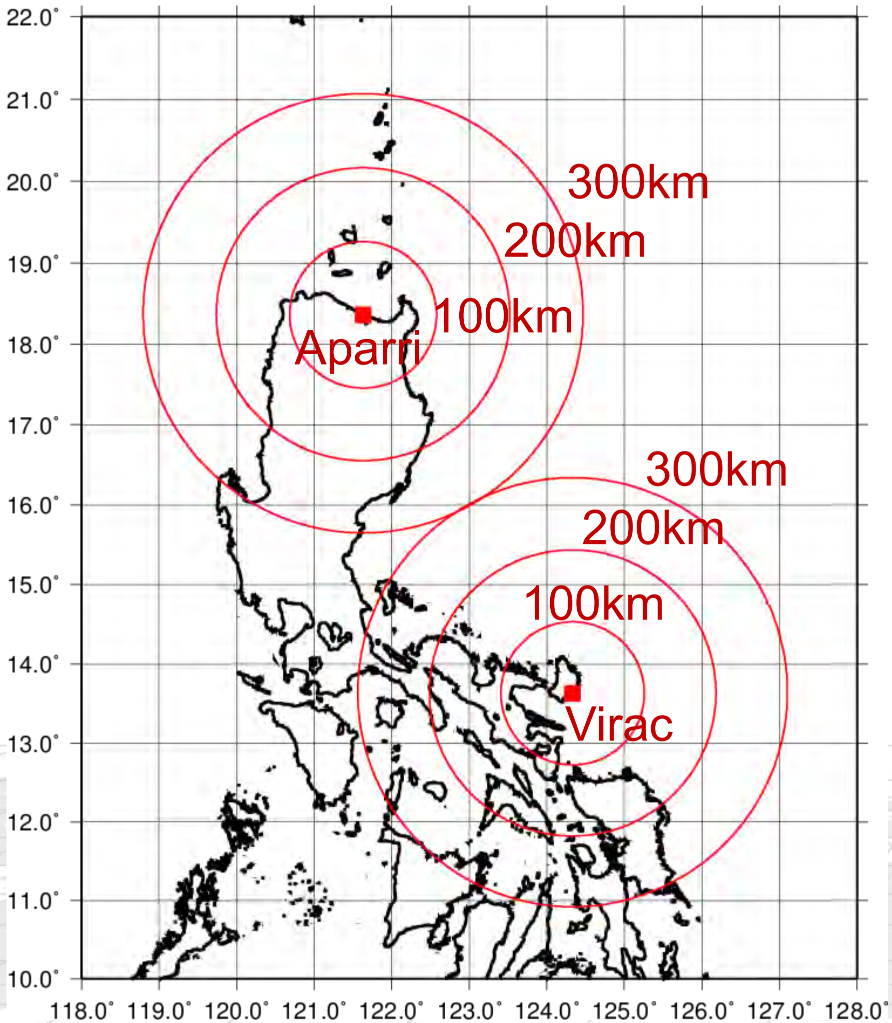
- GSMaP is one of GPM JAXA standard product.
- GSMaP is a blended Microwave-IR product and has been developed in Japan toward the GPM mission.

Flowchart of this study

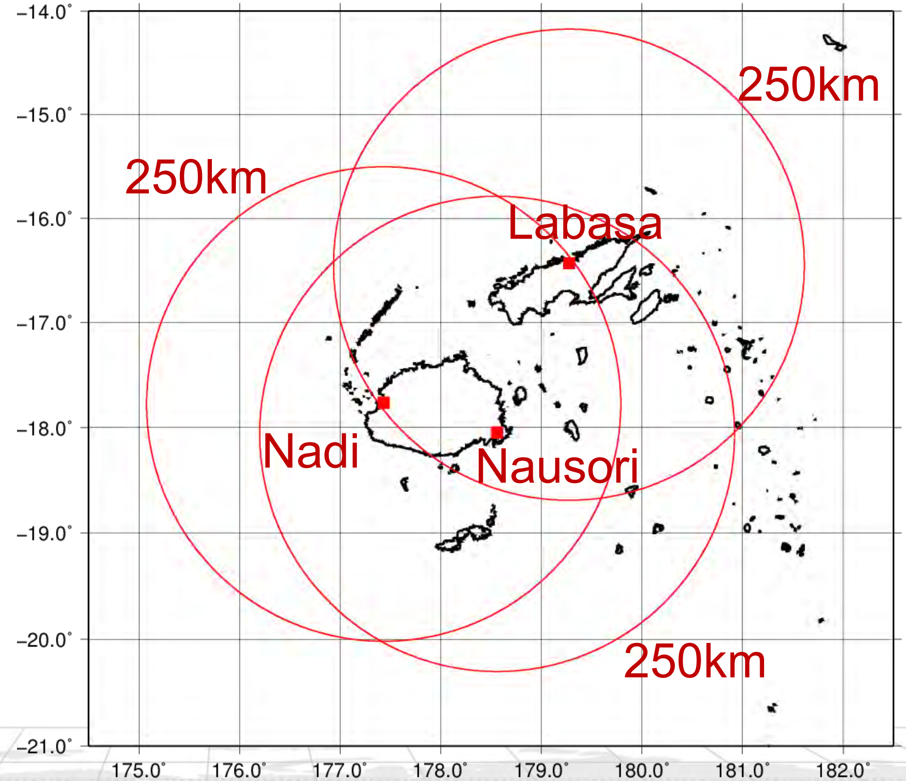


Ground radar coverage

Philippines : 2 radars (Aparri, Virac)



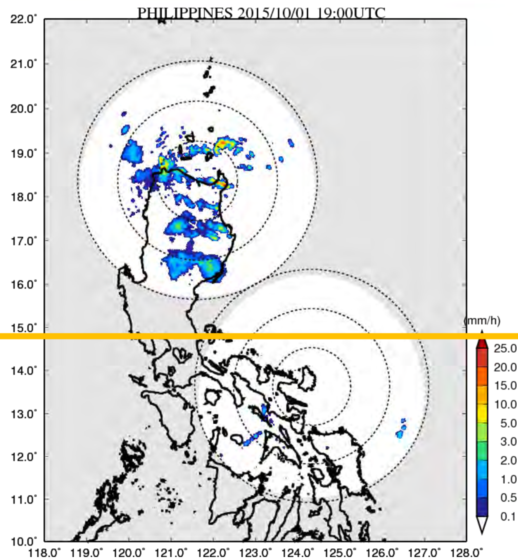
Fiji : 3 radars (Nadi, Nausori, Labasa)



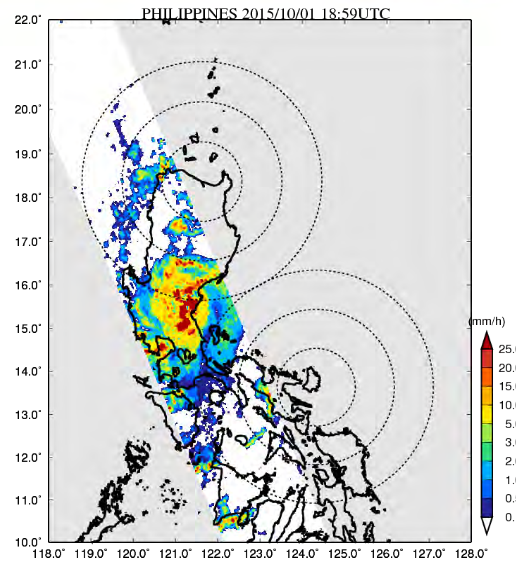
There are wider oceanic areas in Fiji radar coverages, while mountainous areas are included in the Philippines radar coverages.

Radar composite

Ground radar

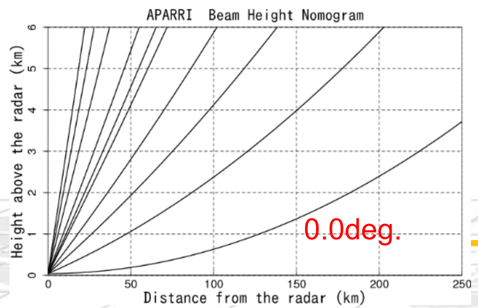


DPR



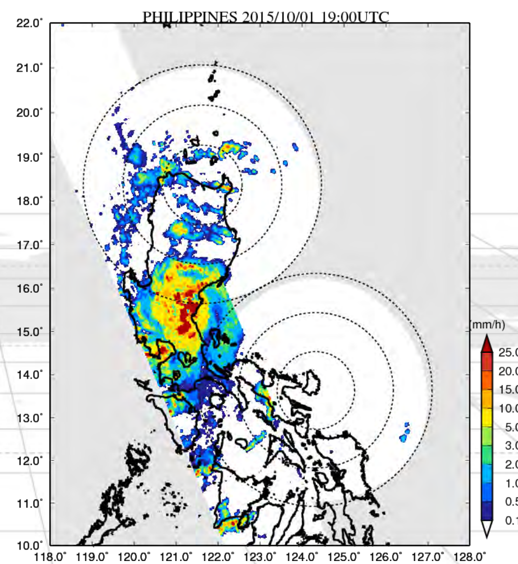
Ground radar calibrated by the DPR

Ground radar beam height



Weighting function

Radar composite



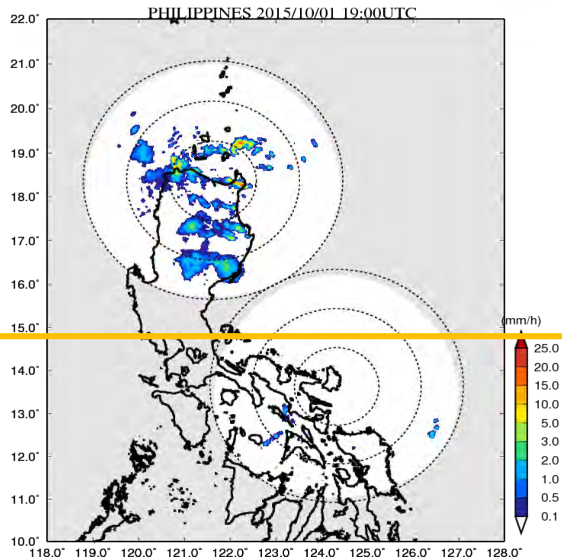
$$G_j = \frac{1}{H_j}\left\{ \frac{1}{H_{rad,j}} \frac{\sum_{i=1}^{N} D_i W_i}{\sum_{i=1}^{N} W_i} + \frac{1}{H_{sat}} D_{sat,j} \right\}$$

Ground Radar *DPR*

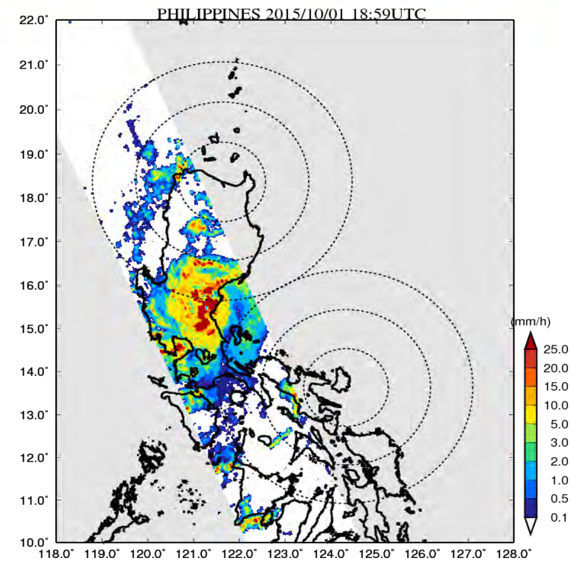
Here, the ground radar beam height was used as a weighting function in merging the ground radar and the DPR.

Hybrid rainfall monitoring - Radar composite

Ground radar

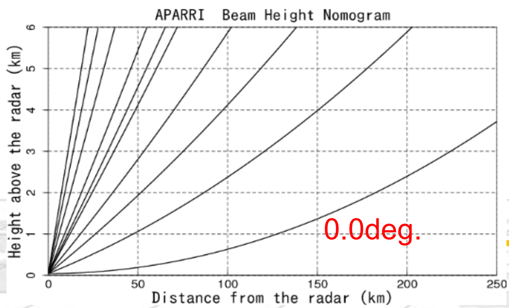


Satellite DPR



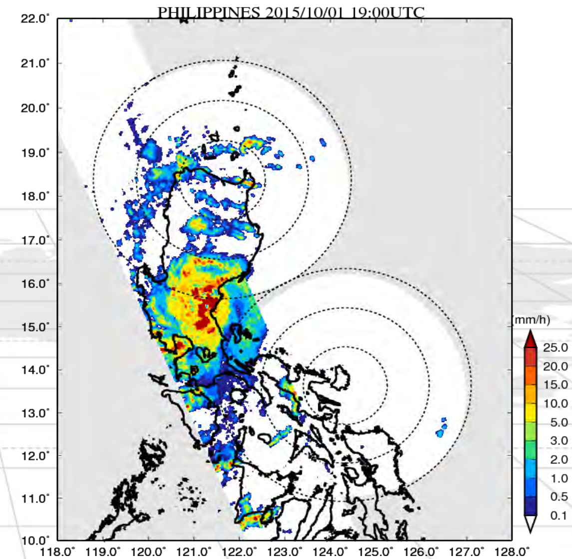
Ground radar calibrated by the DPR

Ground radar beam height



Weighting function

Radar composite



$$G_j = \frac{1}{H_j}\left\{ \frac{1}{H_{rad,j}} \frac{\sum_{i=1}^{N} D_i W_i}{\sum_{i=1}^{N} W_i} + \frac{1}{H_{sat}} D_{sat,j} \right\}$$

Ground Radar *DPR*

Here, the ground radar beam height was used as a weighting function in merging the ground radar and the DPR.

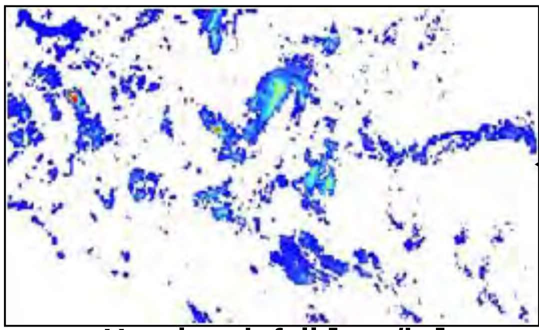
What is “GSMaP-IF version 4.0”?

After GSMaP-IF version 2 focuses on the correction of short term (hourly/daily) rainfall. GSMaP-IF corrects GSMaP by using ground observatory rainfall data taken in synchronization with GSMaP. In Version 4.0, the corrections accuracy have been improved by using a TIN based algorithm.

Input ground observatory data

start time	term	000001	000002	000003
2010/6/17 0:00	24	0	8	5.2
2010/6/18 0:00	24	100	25	58
2010/6/19 0:00	3	0	0	0
…	…	…	…	…

GSMaP Rainfall Data (Original)



Hourly rainfall [mm/hr]

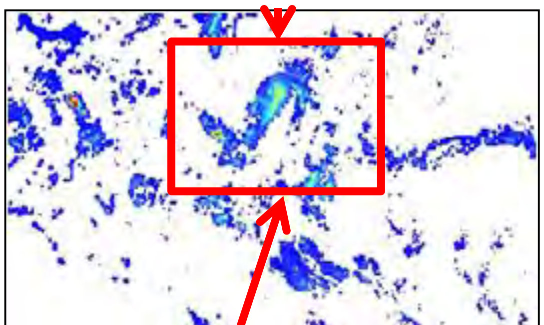
Download

GSMaP-IF

Extracting Subset Area

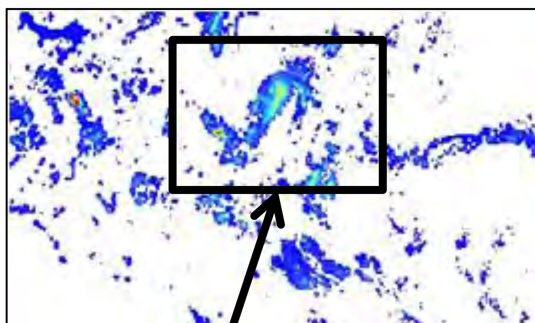
Correction

Version 2/3 real-time Corrected Data



Correction Area

Version.1 Corrected Data



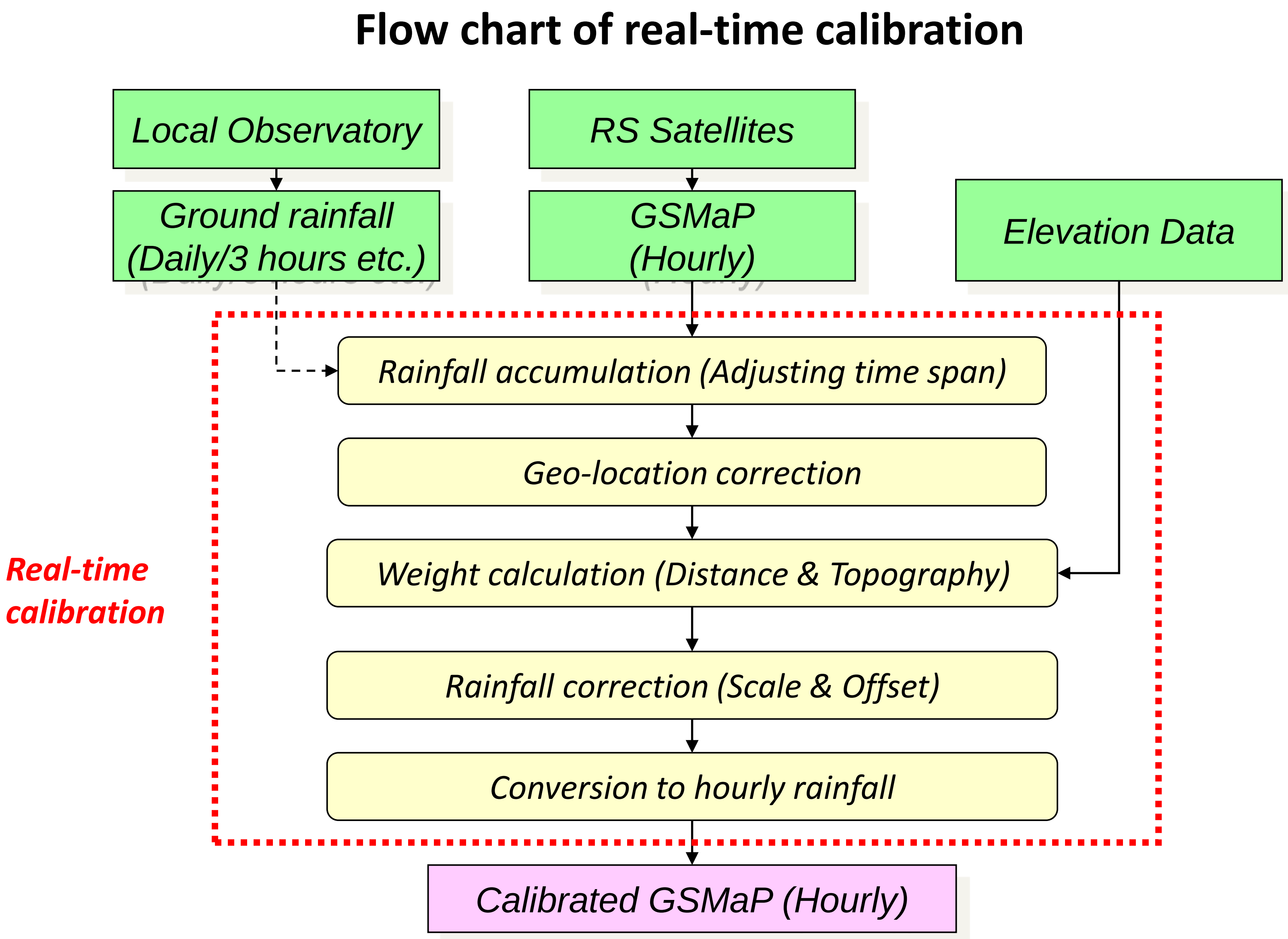
Correction Area

Subset Data

Lat	Lon	Rainfall
N31.75	E75.85	1.456448
N31.75	E75.95	1.362135
N31.75	E76.05	1.77756
N31.75	E76.15	0.274333
N31.75	E76.25	1.046201
N31.75	E76.35	0
N31.75	E76.45	0

Subset Area

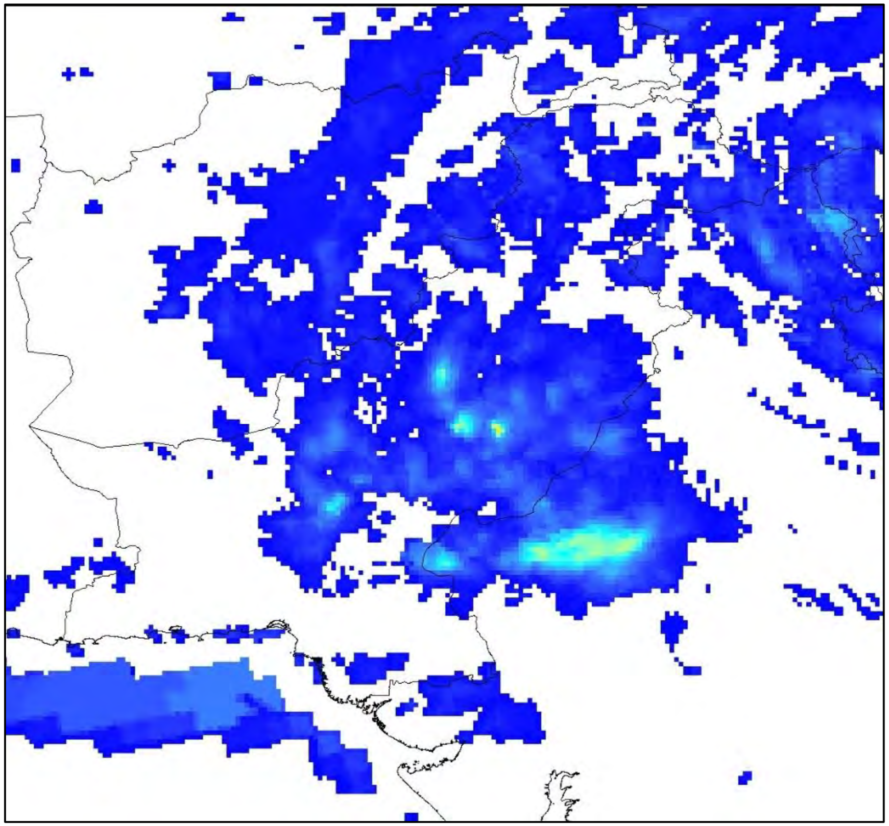
GSMaP-IF: Methodology



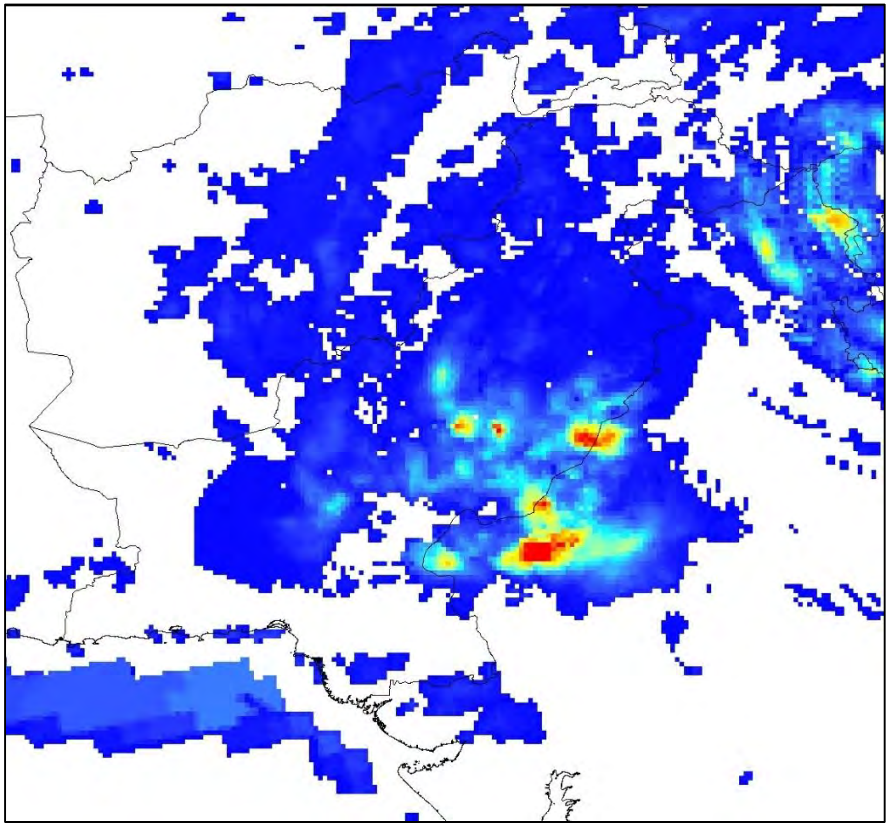
Triangulation based algorithm (ver. 4.0)

✓ The rainfall value is corrected by using the correction factor.

Before

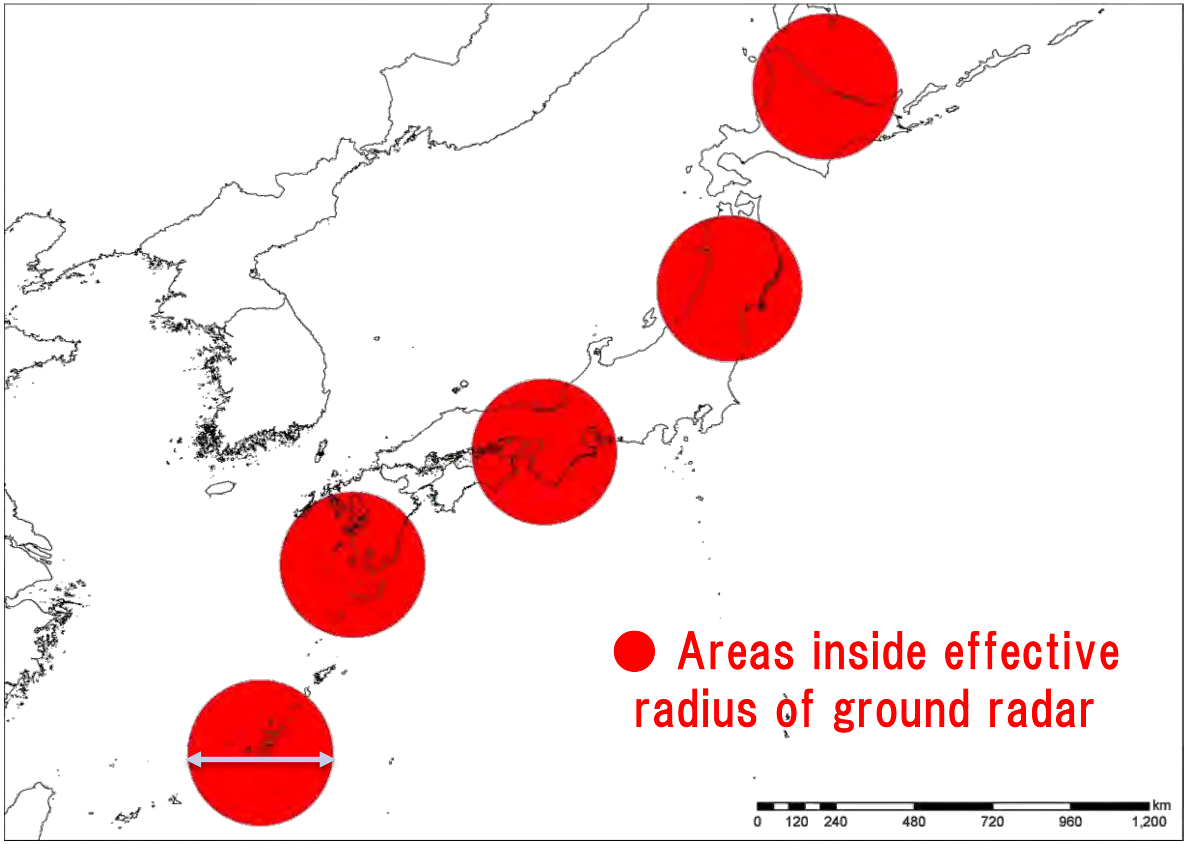


After



An experiment of data fusion of ground weather radar and satellite sensor

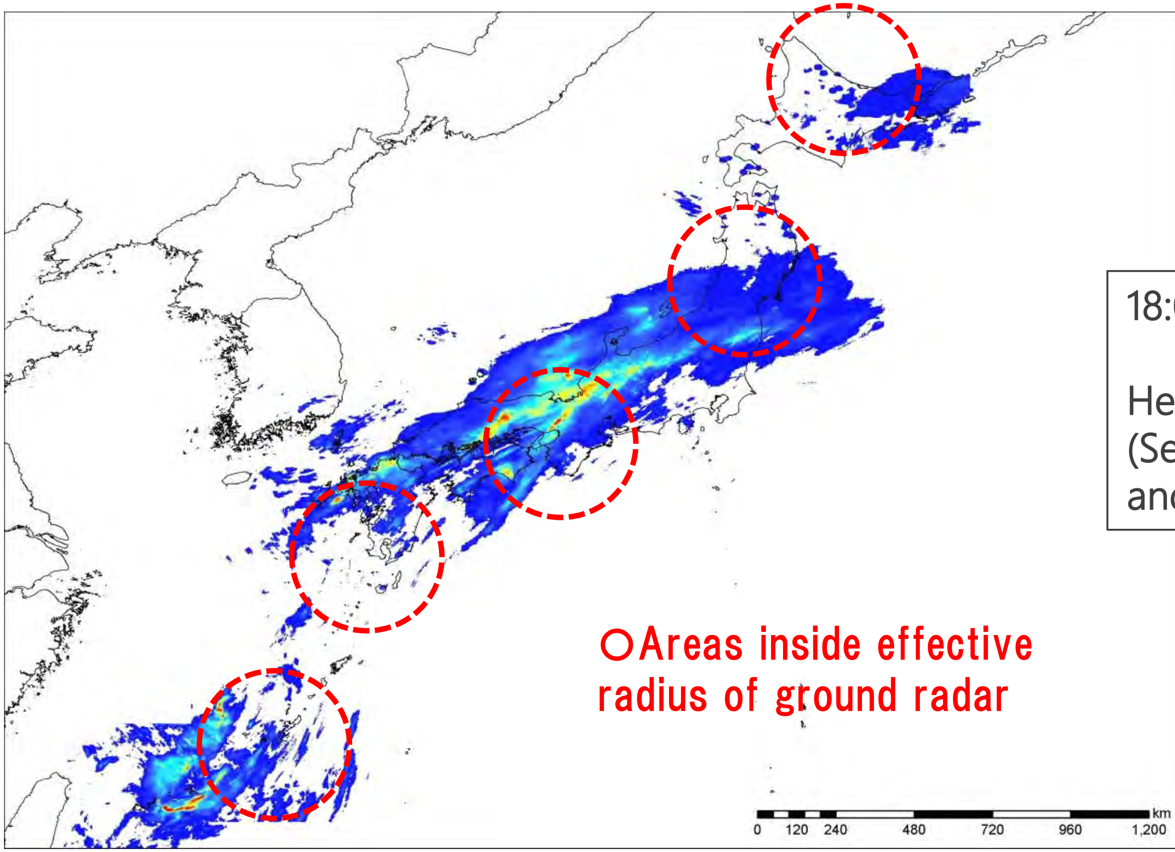
✓ Ground weather radars were virtually located at interval of approx. 600km distance.



200km

An experiment of data fusion of ground weather radar and satellite sensor

Hourly rainfall based on ground weather radar

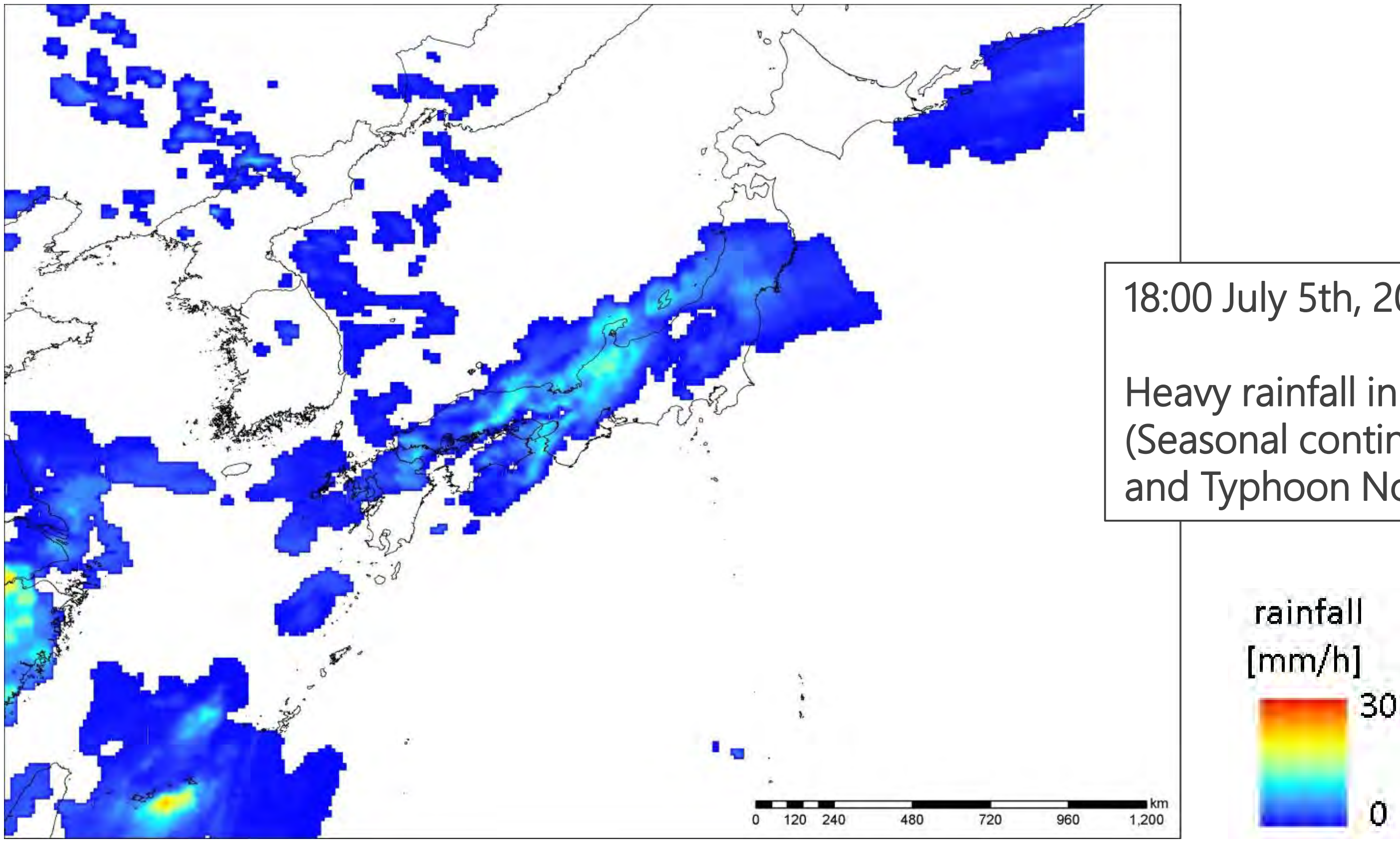


18:00 July 5th, 2018

Heavy rainfall in July, 2018 (Seasonal continuous rainfall and Typhoon No.7 in 2018)

An experiment of data fusion of ground weather radar and satellite sensor

Hourly rainfall based on satellite data (GSMaP)

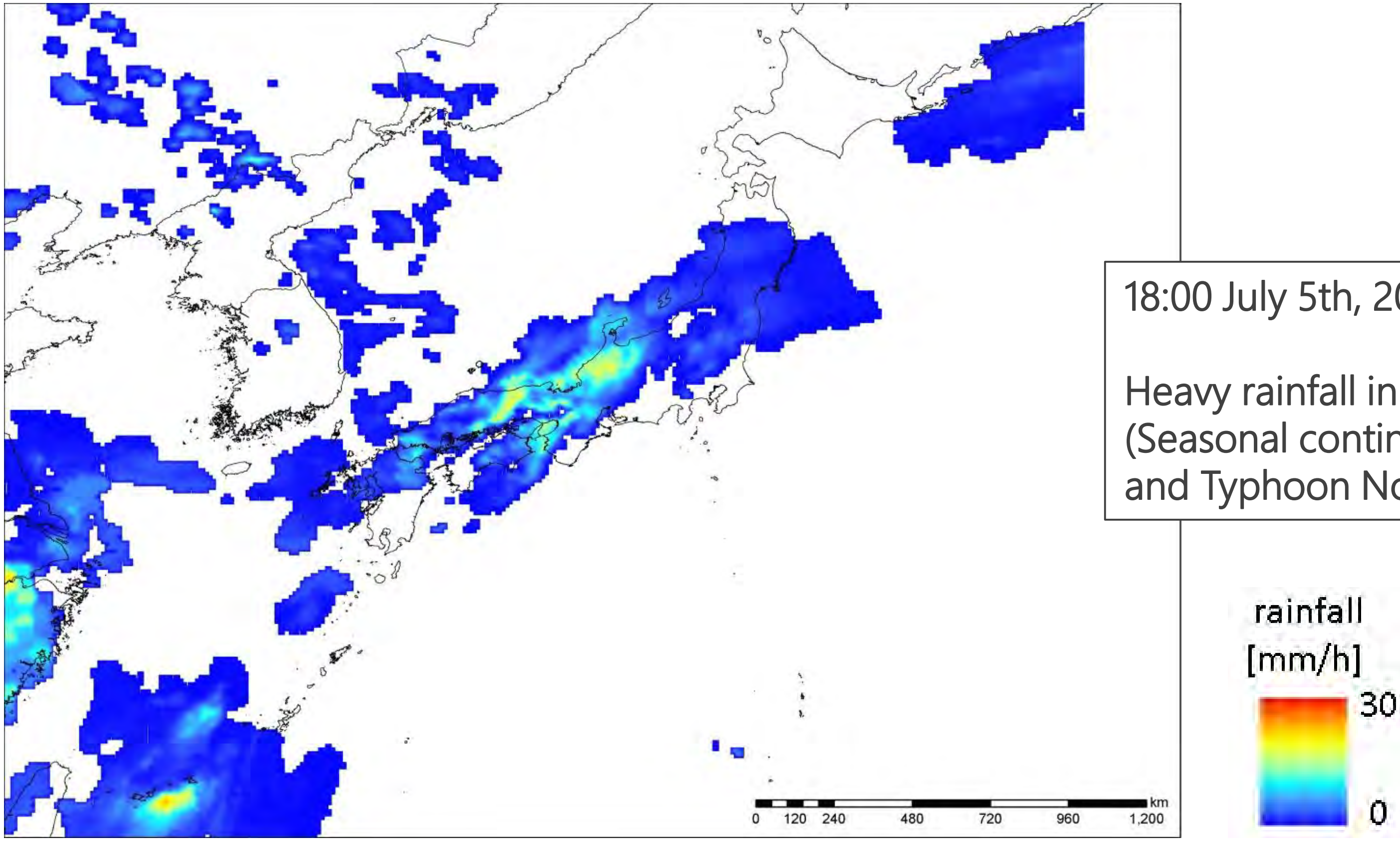


18:00 July 5th, 2018

Heavy rainfall in July, 2018
(Seasonal continuous rainfall and Typhoon No.7 in 2018)

地上気象レーダ雨量を使用したGSMaPの補正と合成

Hourly rainfall based on calibrated satellite data (GSMaP-IF)

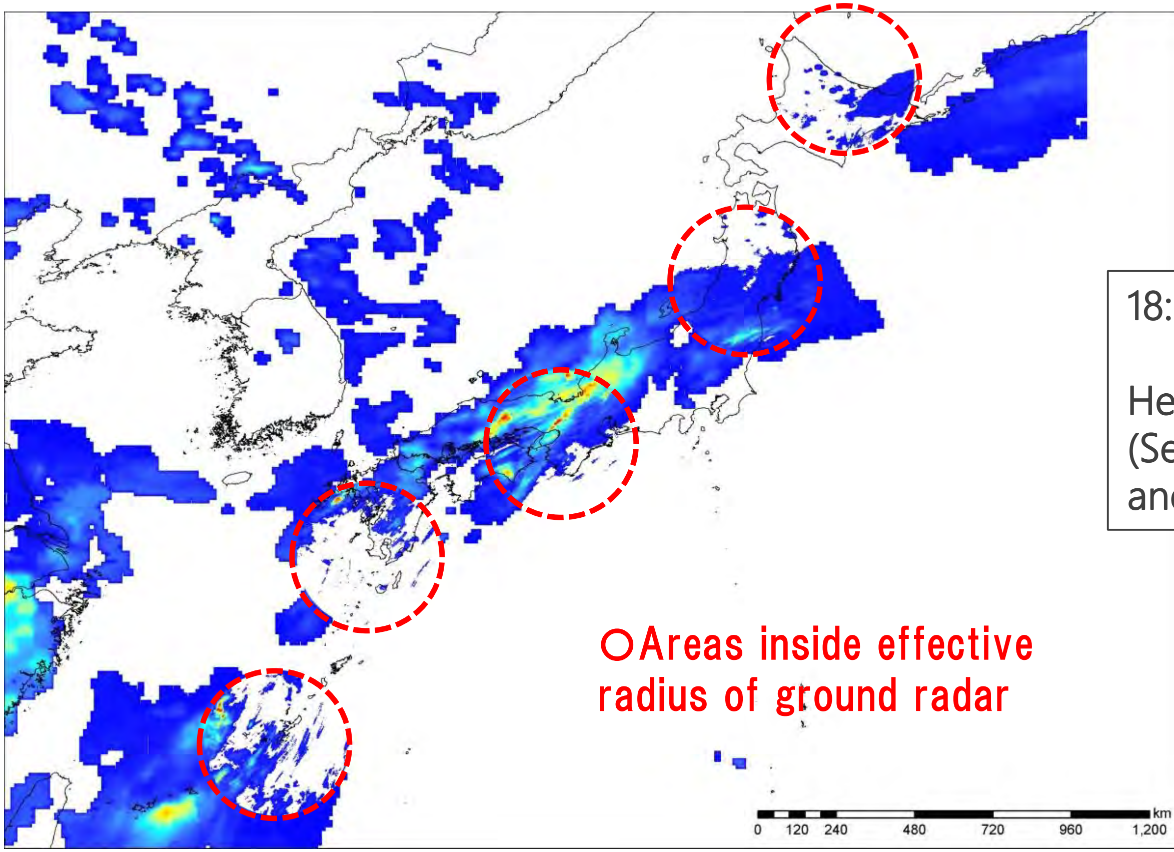


18:00 July 5th, 2018

Heavy rainfall in July, 2018
(Seasonal continuous rainfall and Typhoon No.7 in 2018)

An experiment of data fusion of ground weather radar and satellite sensor

Fused hourly rainfall based on ground weather radar and calibrated satellite data



18:00 July 5th, 2018

Heavy rainfall in July, 2018 (Seasonal continuous rainfall and Typhoon No.7 in 2018)

Research activities and prototype in the Philippines

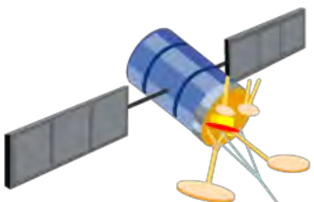
Pilot Study in the Philippines

GSMaP rainfall archives are analyzed by a machine learning method (RBFN), and critical lines (CLs) of hourly rainfall and soil moisture index (SMI) are selected.

The system monitors rainfall in real-time and determines the landslide warning level.

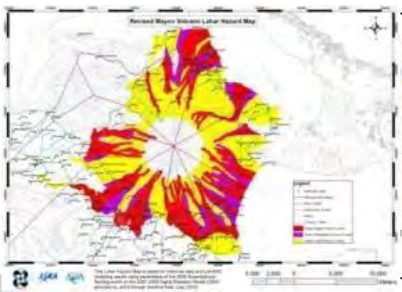
Rainfall monitoring — **Sensor network**

AWS

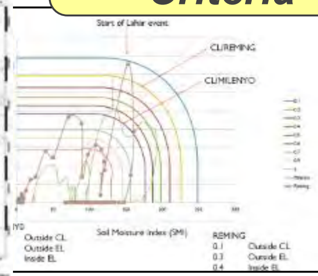


GSMaP-Now Satellite

Model preparation — **Hazard maps, Criteria**

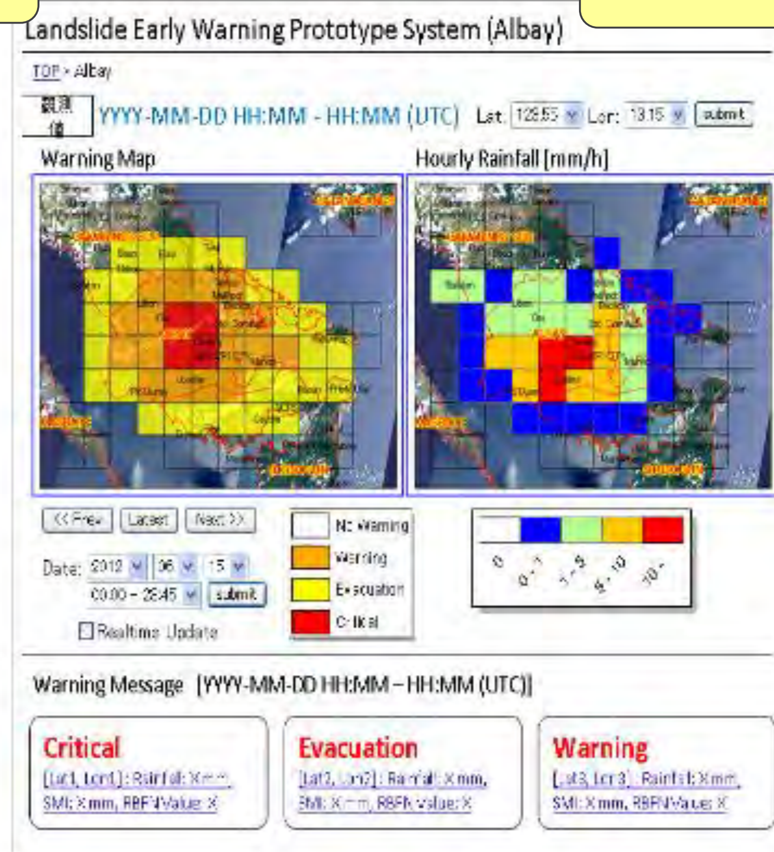


Maps



Warning criteria

System Prediction — **System**



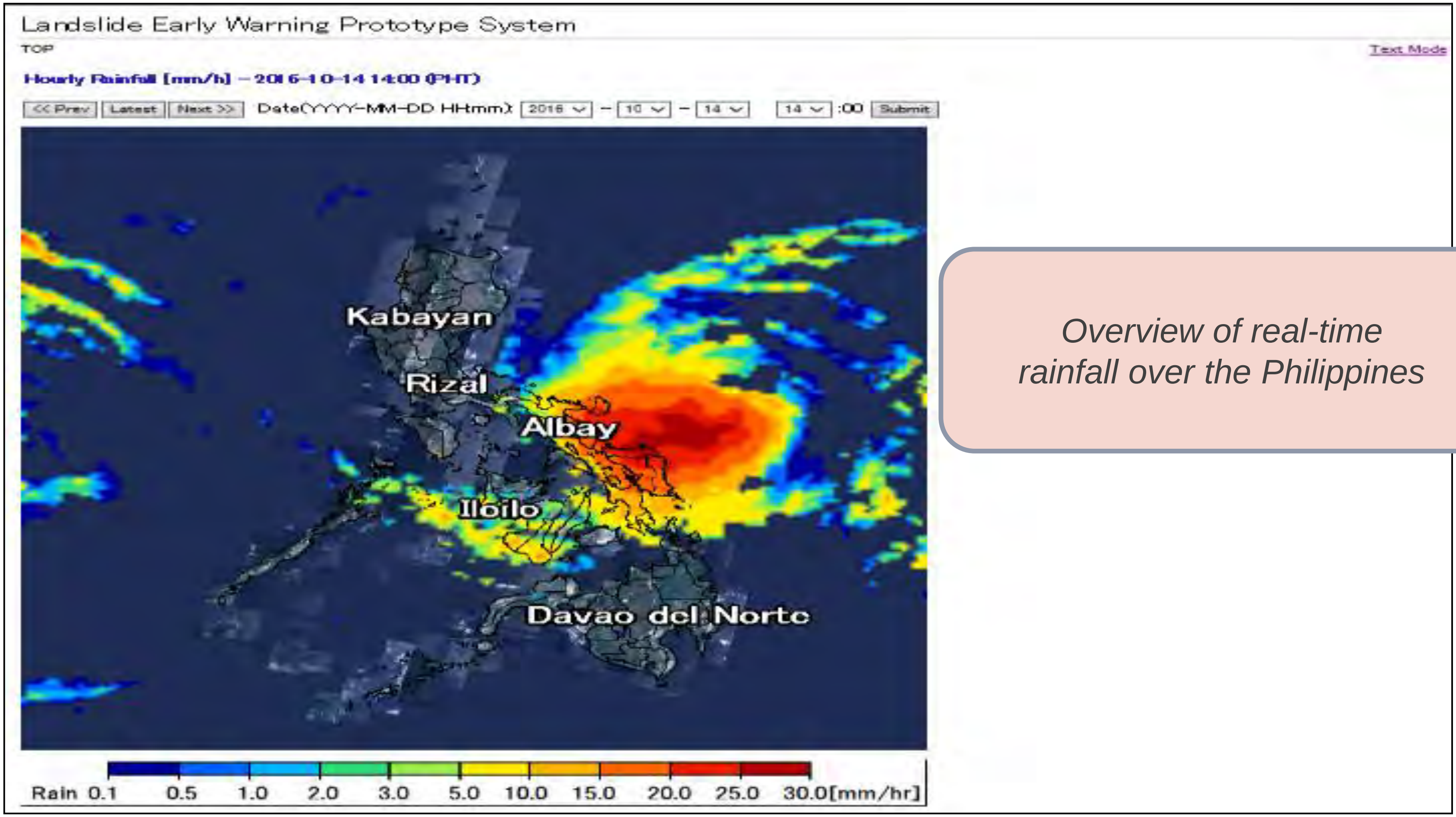
Application

Analysis / Warning

DRR Agency/ Local Government Unit (LGU)

GLAWS – A web based landslide warning system

Providing "real-time landslide risk level" at each 10 by 10km mesh.



Overview of real-time rainfall over the Philippines

NTT DATA

Case Study for Rizal (Typhoon NONA)

Typhoon Nona, a powerful tropical cyclone, struck the Luzon island in Dec. 2015 causing several big landslides destroying houses, roads and other facilities.

Cited from Local News (GMA News: www.gmanetwork.com)

3 killed, 1 missing in Quezon province landslide

GMA News *Published December 19, 2015 4:22pm*

Three people were reported killed and one was missing in a landslide that hit Barangay Tanauan, Real, Quezon on Saturday afternoon.

Citing initial information, Provincial Disaster Risk Reduction and Management Office chairman Dr. Henry Buzar told GMA News that the ***landslide occurred at about 1:30 p.m.*** *amid continuous heavy rains in the province.*

Actual Landslide Survey

Since Rizal province has mountainous topography, many landslides were caused by heavy rainfall events. Recently, several landslides happened on Dec. 2015.

Marikina-Infanta Road

Surveyed on March.10th 2016.

Antipolo city

Surveyed on August.10th 2016.

Case Study for Rizal (Typhoon NONA)

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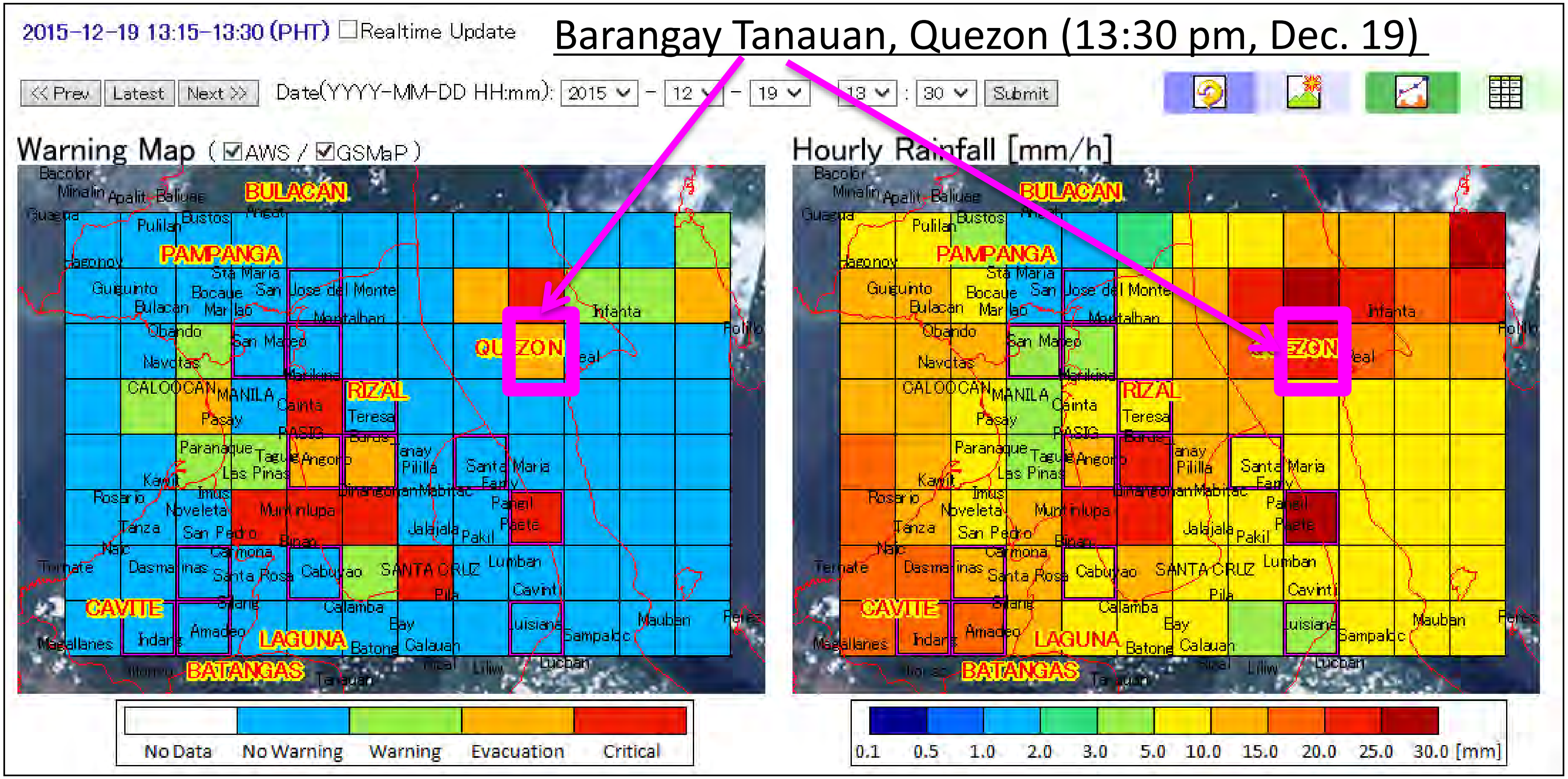

Case Study for Rizal (Typhoon NONA)

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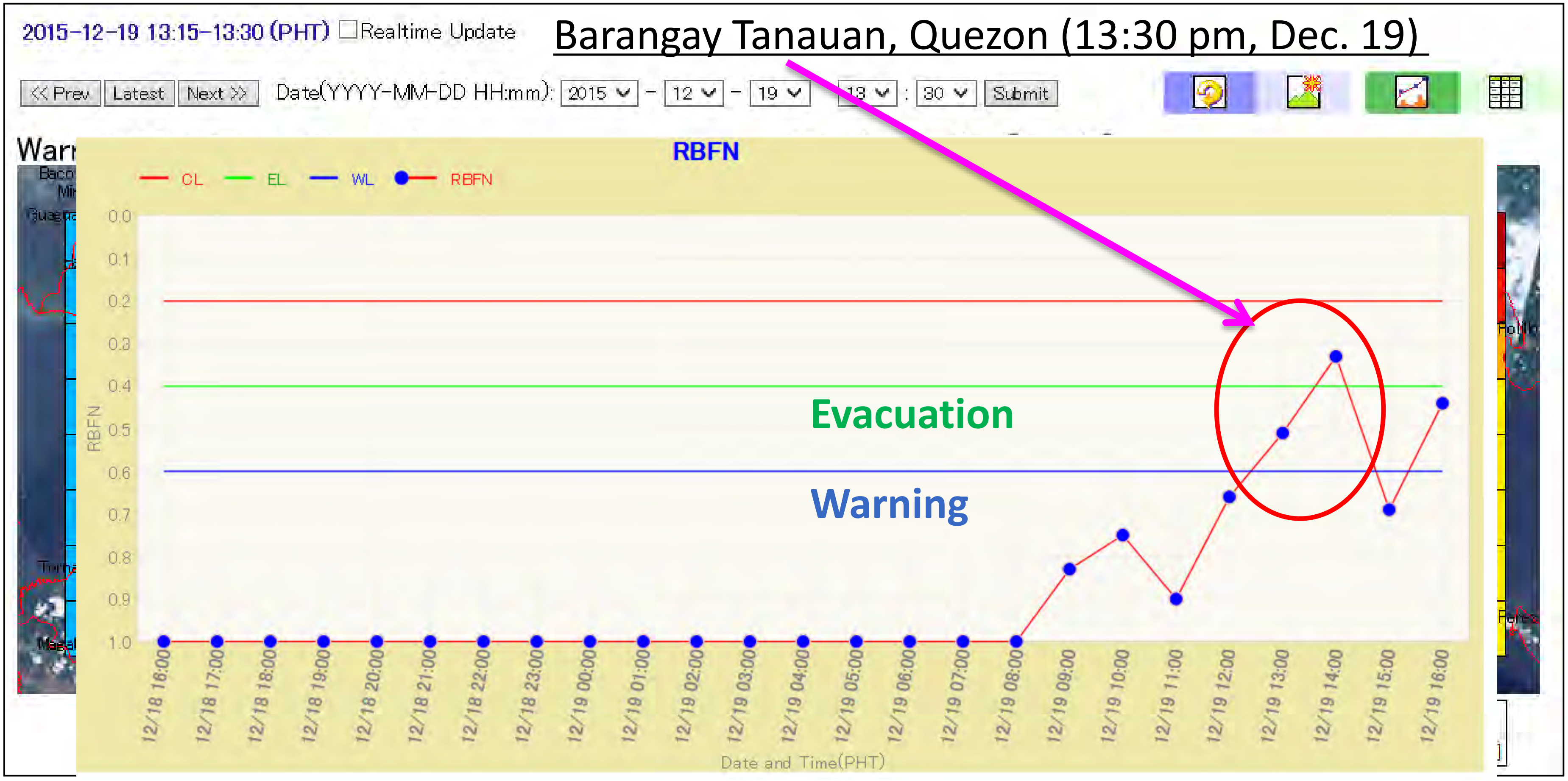

Assessment

Assessment results of landslides showed good results induced by heavy rainfall.

Two cases were successfully warned.

Adjustment to persistent small rain will improved by combining with ground weather radar

List of landslides happened in Rizal Province since 2014

No.	Date	Warning	Damage	Cause
1	Dec.19, 2015	Yes	3 killed 1 missing	Tropical storm "Nona" (international name: Melor)
2	Oct. 15, 2016	Yes	3 killed 4 causalities	Tropical storm "Karen" (international name: Sarika)
3	March 10, 2016	No	3 killed	**Not rainfall-induced landslide.** Caused by construction problem.
4	Dec.15, 2015	No	1 killed 4 causalities	Persistent rains spawned by Tropical storm "Nona" (international name: Melor)
5	July 23, 2014	No	1 killed	Persistent rains which saturated the ground

Will be improved by combining with ground weather radar

Rizal Pilot Study – Training and Calibration

A local calibration and training on the use of WEB-based Landslide Warning System (GLAWS) was conducted in Antipolo City (Barrangay-Level) and Rizal Province (Municipal Level) together with National DRR agencies (MGB,PAGASA,PHIVOLCS).

NTT DATA

NTT DATA

Global IT Innovator