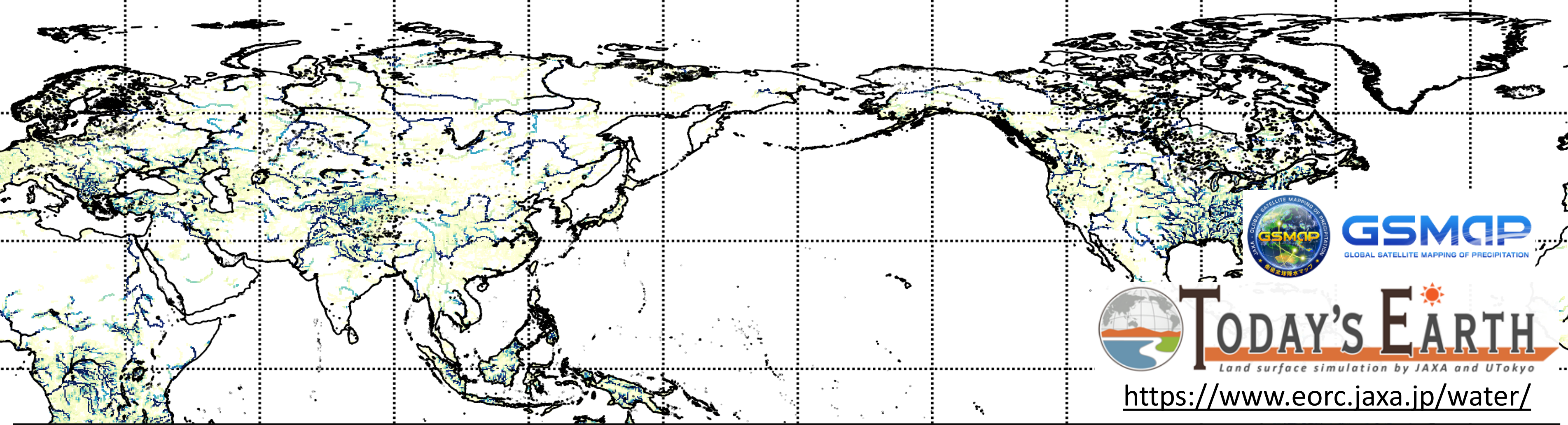


https://www.eorc.jaxa.jp/water/

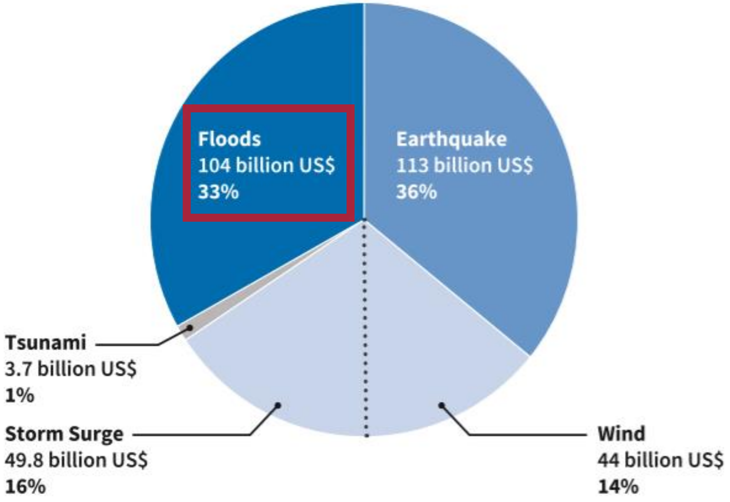
Flood Prediction for Japan and World: Synergy by Physical Modeling and Machine Learning

Kei Yoshimura

Institute of Industrial Science, The University of Tokyo
Earth Observation Research Center, JAXA

Background

Average Annual Loss (Economic) caused by natural disasters



Source: UNISDR; data from global risk assessment

- Floods accounts for 1/3 of global Average Annual Loss. [UNISDR, 2015]
  - Floods caused 5 in top 10 largest economic loss induced by natural disasters. [EM-DAT]

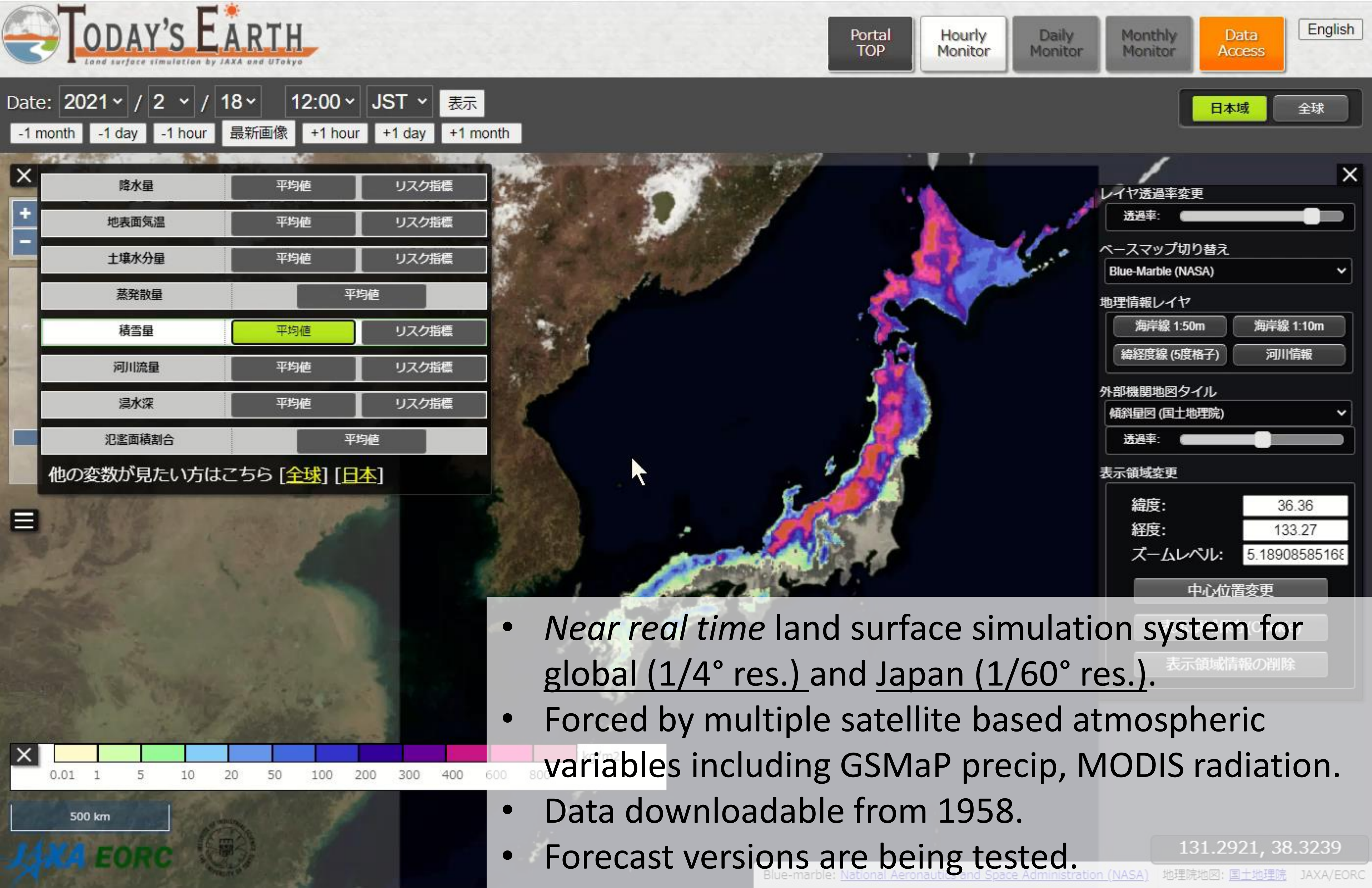
✓ Flood Early Warning is an effective mean for disaster reduction.

- Extend the time to evacuate / prepare for flood defense.
- Offer a effective information for river management officers.
- Increase the disaster awareness. [Katada et al., 2003]

TODAY'S EARTH — Land surface simulation by JAXA and UTokyo

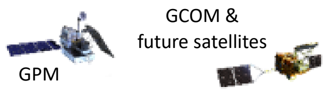
https://www.eorc.jaxa.jp/water/

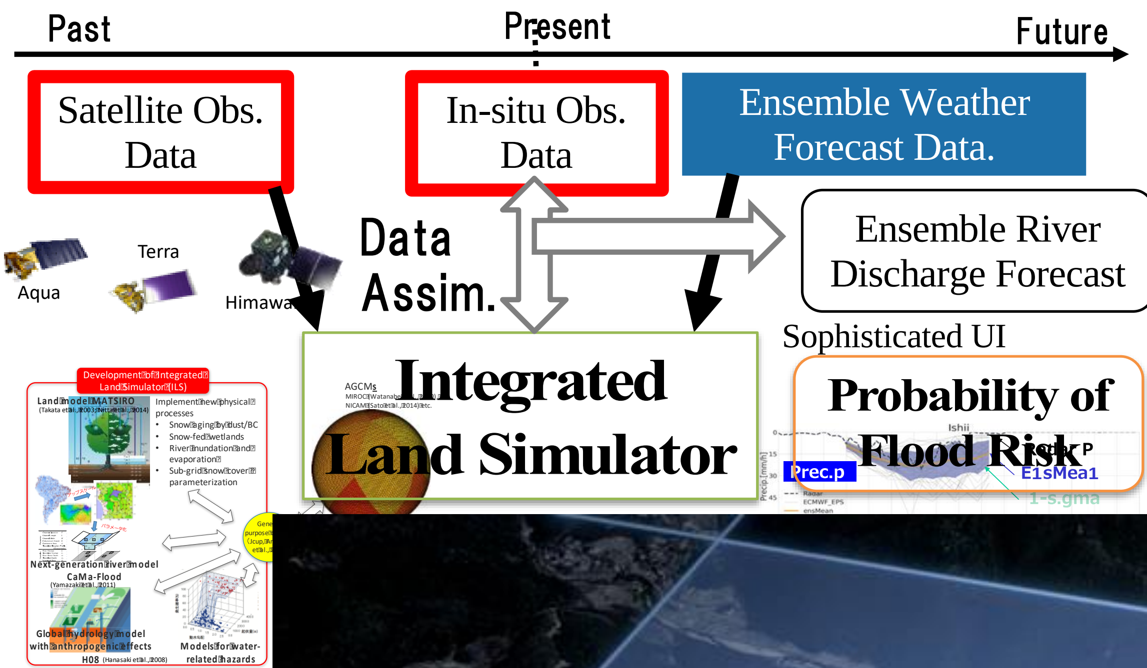
Today's Earth system



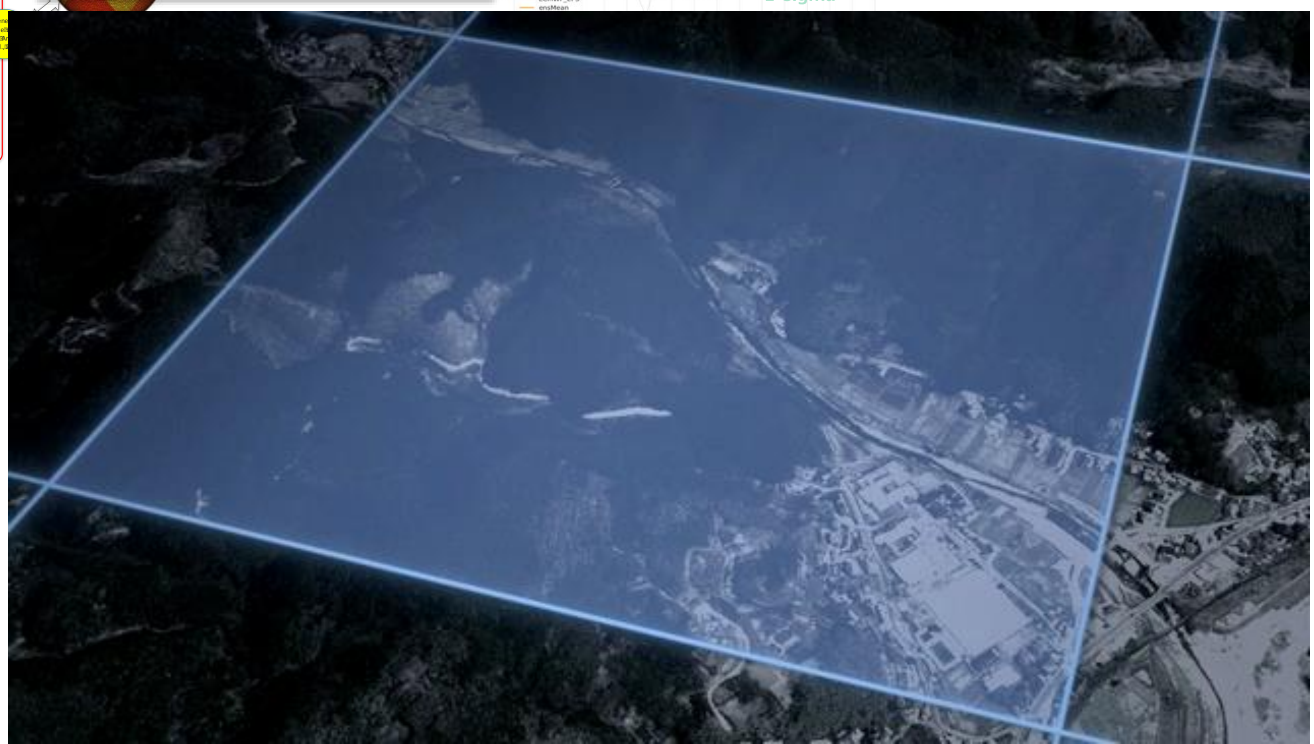
- *Near real time* land surface simulation system for global (1/4° res.) and Japan (1/60° res.).
- Forced by multiple satellite based atmospheric variables including GSMaP precip, MODIS radiation.
- Data downloadable from 1958.
- Forecast versions are being tested.

Structure of Prediction using Today's Earth - Japan

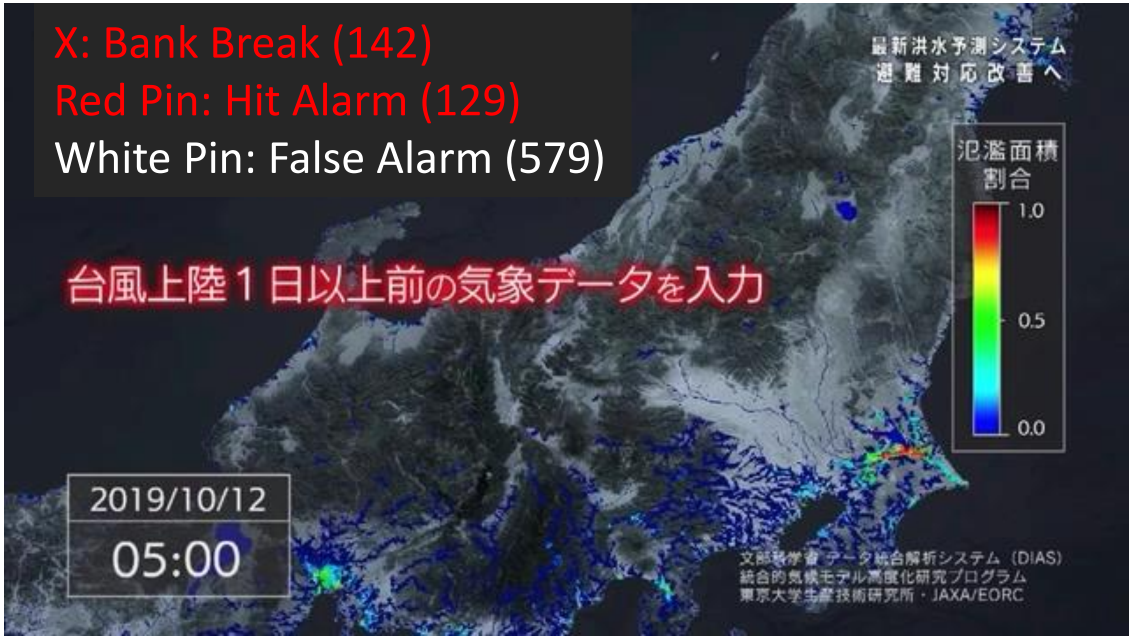




We developed a reliable *flood prediction system over all Japan*, aiming to provide those information well before hazard (1-2 days ahead) in horizontally 1km resolution.



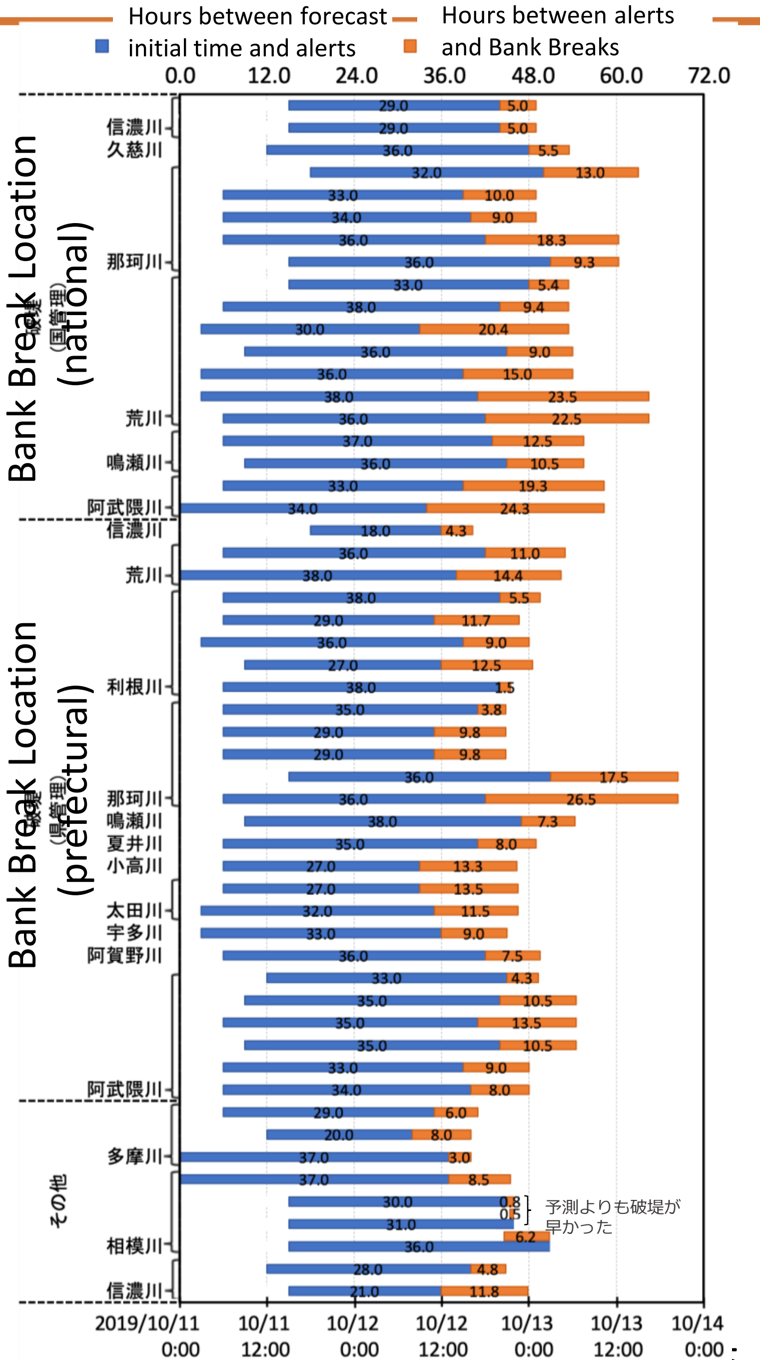
Predictability for Floods by Hagibis



©NHK

According to authority, there were **142 levee-broken sites**. TE-Japan **successfully gave "alerts" at 129 sites** (i.e., 1/200yr water level) with sufficient lead time (in average 32.3 hours). Levees were destroyed 8.5 hours later than the "alerts".

False alarm rate is about **90% at 3am Oct 11**, but decreased to **70% since 9am Oct 11**, and reached 60% at 9pm Oct 12, when actual flooding started to occur.



Ma et al., in revision.

Ohki et al. 2020

Fusion with Satellite Observation (SAR)

Probability of class i $P(F_i|\boldsymbol{x}) = \dfrac{P(F_i)P(\boldsymbol{x}|F_i)}{\sum_{j=0}^{3} P(F_j)P(\boldsymbol{x}|F_j)}$

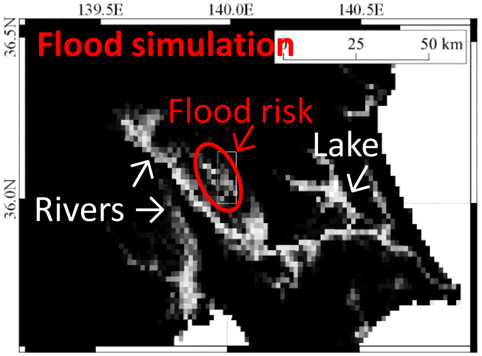
SAR data $\boldsymbol{x} = \begin{pmatrix} \text{Co-event amplitude} \\ \text{Pre-event amplitude} \\ \text{Coherence difference*} \end{pmatrix}$

*co-event coherence − pre-event coherence

Prior probability

Probability density function of SAR data for each class

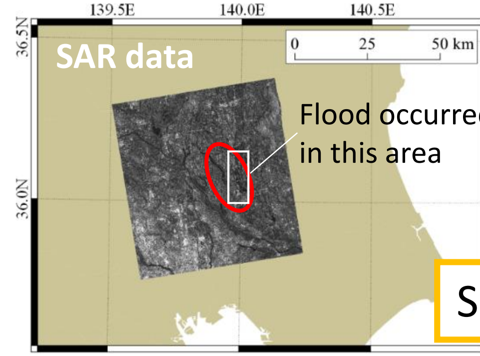
TE



$P(\boldsymbol{x}|F_i) = \mathrm{N}(\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i)$

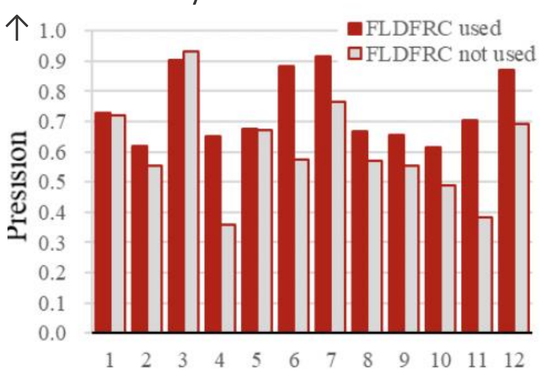
N : Gaussian Distribution

$\boldsymbol{\mu}, \boldsymbol{\Sigma}$: Parameters of N (should be set along the incidence angle)



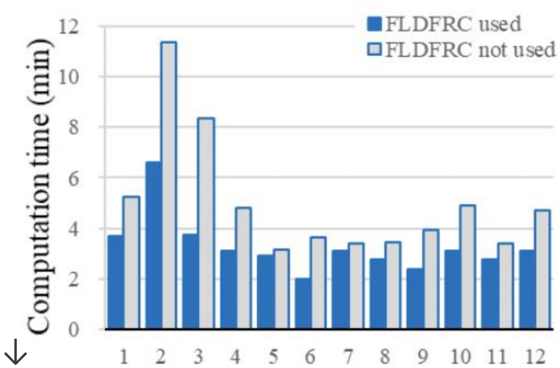
Satellite

Better accuracy

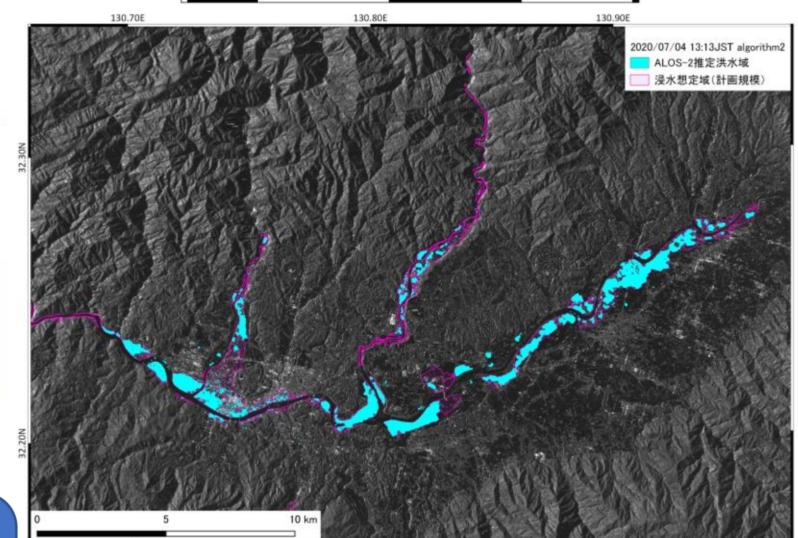


(b)

Better efficiency



(c)

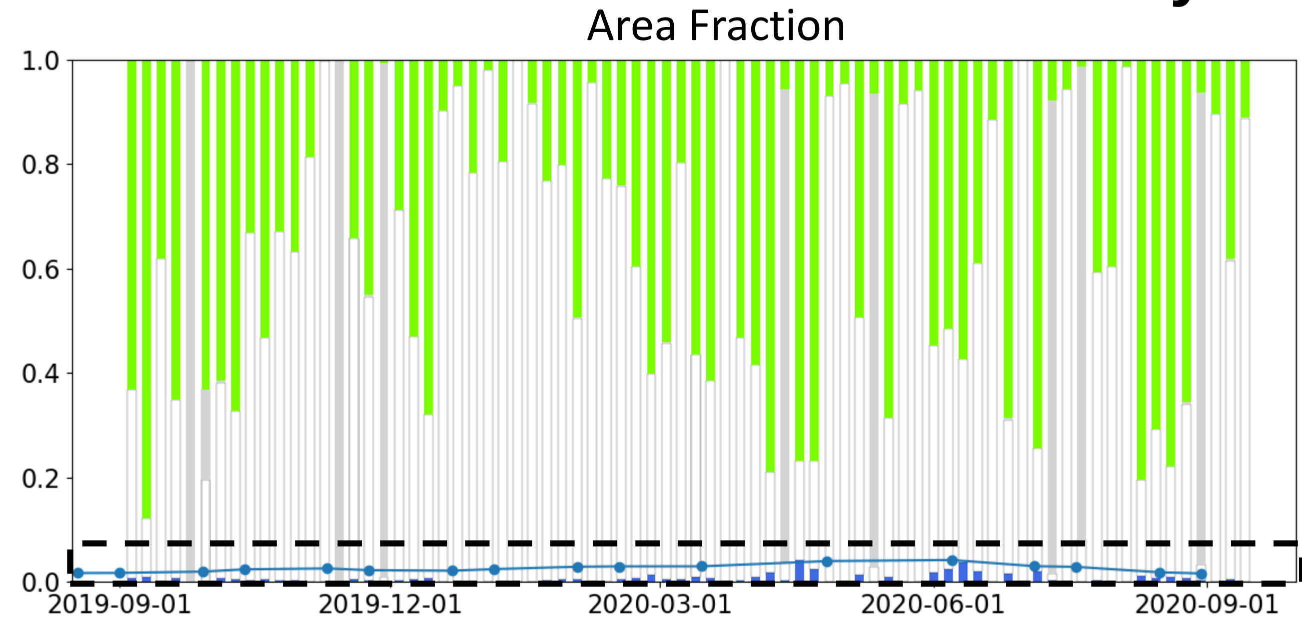


Even though TE-J's low resolution (i.e., 1km), using predicted flood fraction as prior helps to improve the SAR-based (3m) inundation estimates.

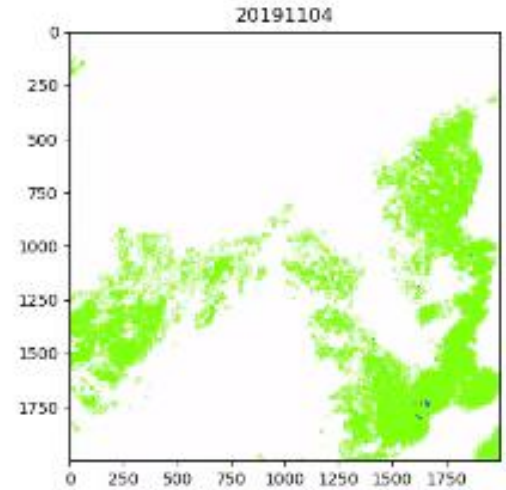
Estimate of inundation is promptly announced in case of July flood 2020.

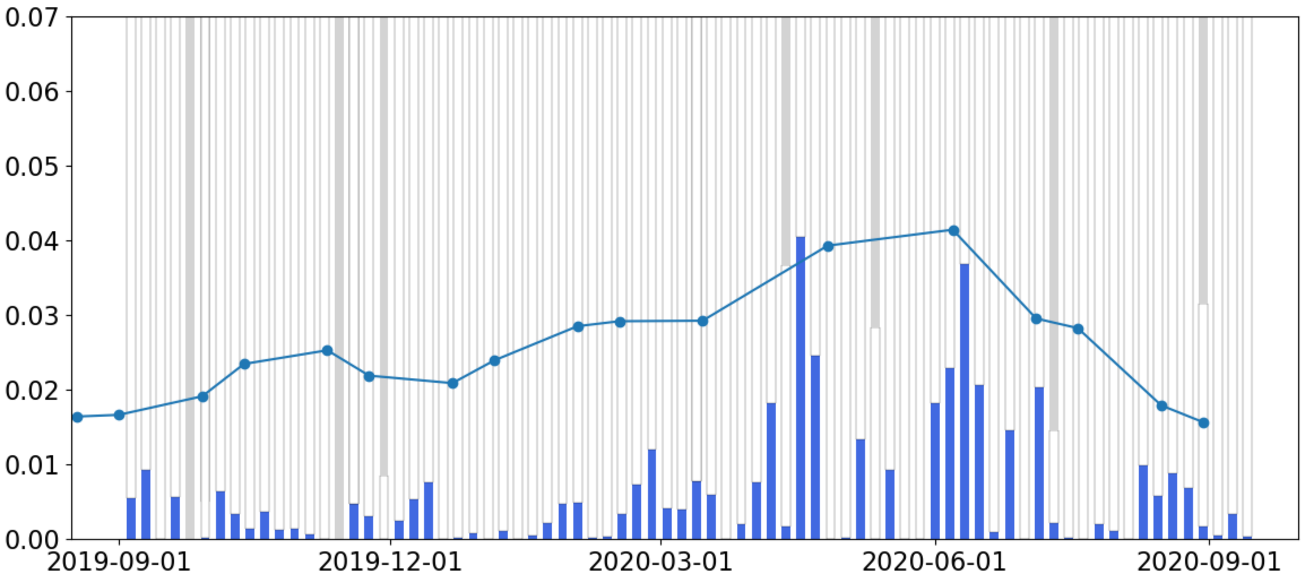
https://www.eorc.jaxa.jp/ALOS-2/img_up/jdis_pal2_heavyrain_kyushu_20200706.htm

Cloud-free observation of water area by SAR

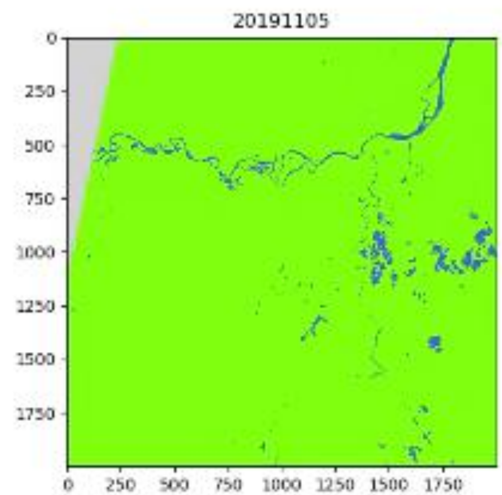


Optical





SAR



時系列

Global (Realtime) SAR Water Area Analysis

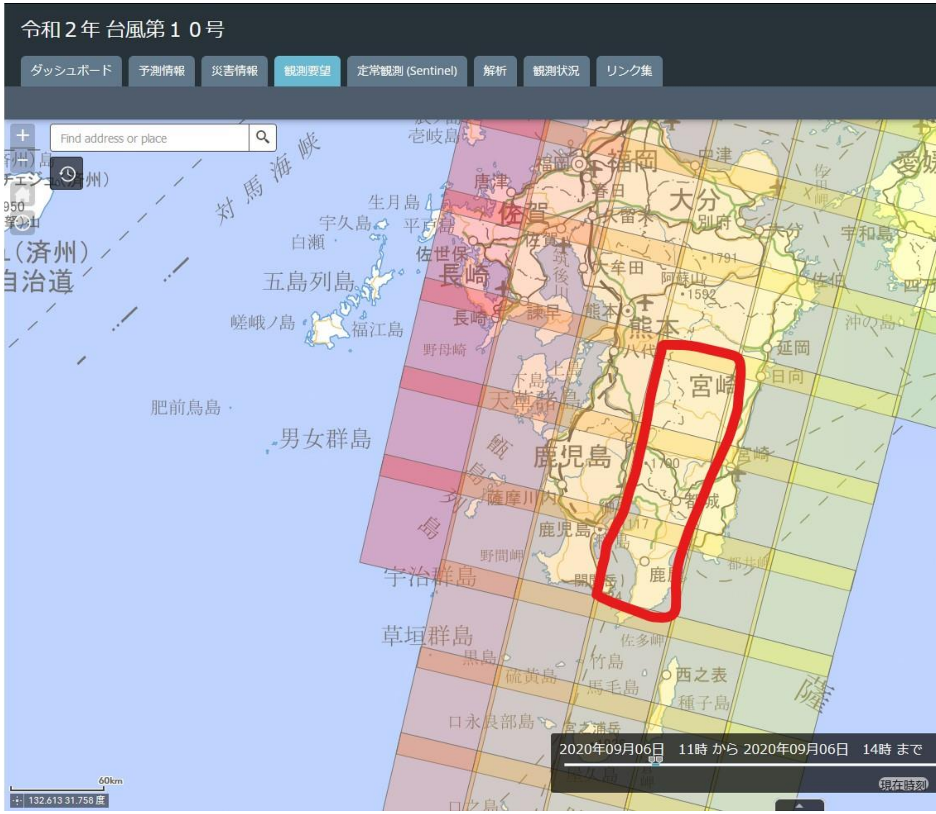
- Land-water map during 2020/8/10~6.

Arai et al., in prep.

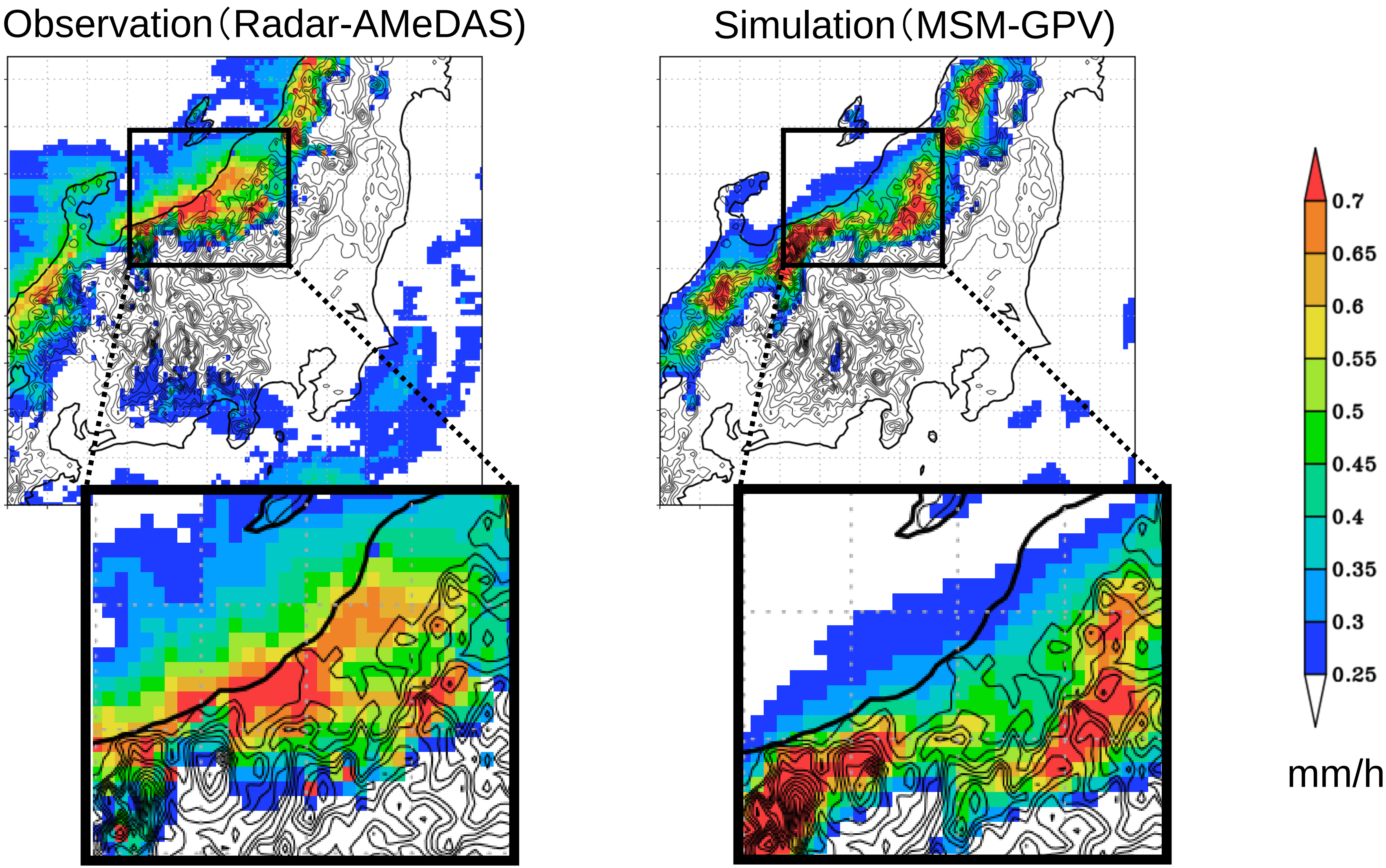
Using TE-J for “One-stop System” by NIED/SIP

TE-Japan started providing its 39-hour prediction to “One-stop System” developed by NIED. It assists the responsible river-management bureau of MLIT to make decision where to shoot by Palsar-2 on ALOS-2, and to request International Charter. It has been used for July heavy rain event and Typhoon 10 in September.

ALOS-2 intensive observation was finally reserved by a meeting at 10:30pm on Sep 5 for 1pm shots on Sep 6. ➔



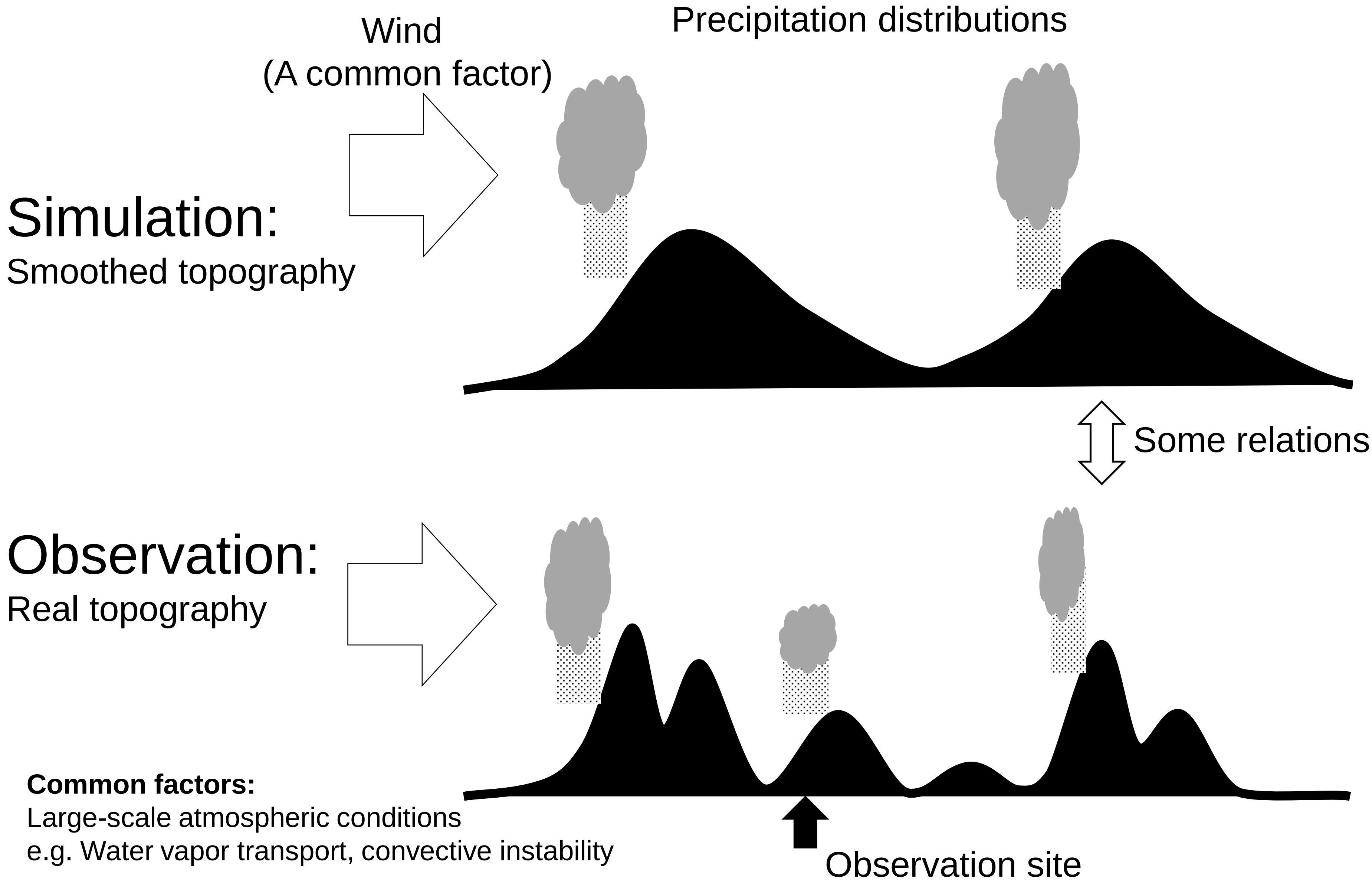
Difficulty of local precipitation forecasts



Monthly precipitation in January (3-year averaged from 2015 to 2017)

Precipitation biases ← incompleteness of numerical models

Orographic precipitation



Common factors:
Large-scale atmospheric conditions
e.g. Water vapor transport, convective instability

Machine Learning Method

Model: **Regression model** of SVM : SVR (e1071 package of R)

Input object (Feature vectors):

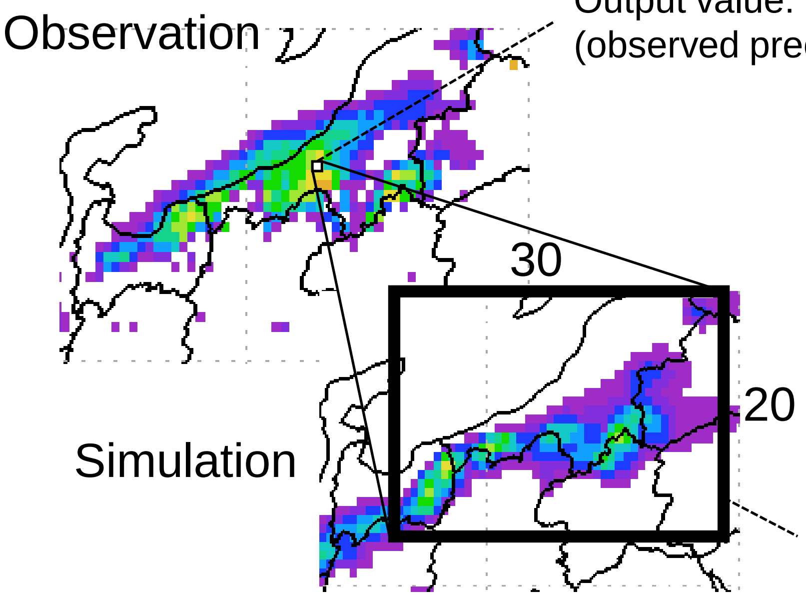
Simulated precipitation (MSMGPV) : 30x20 grids (0.06 deg/grid, 3 hours)

Desired output value (Supervisory signal):

Observed precipitation, which is centered around the area of input object, at each grid (0.06 deg/grid,3 hours)

Learning data: January from 2011 to 2017 except for test data (6 years) .

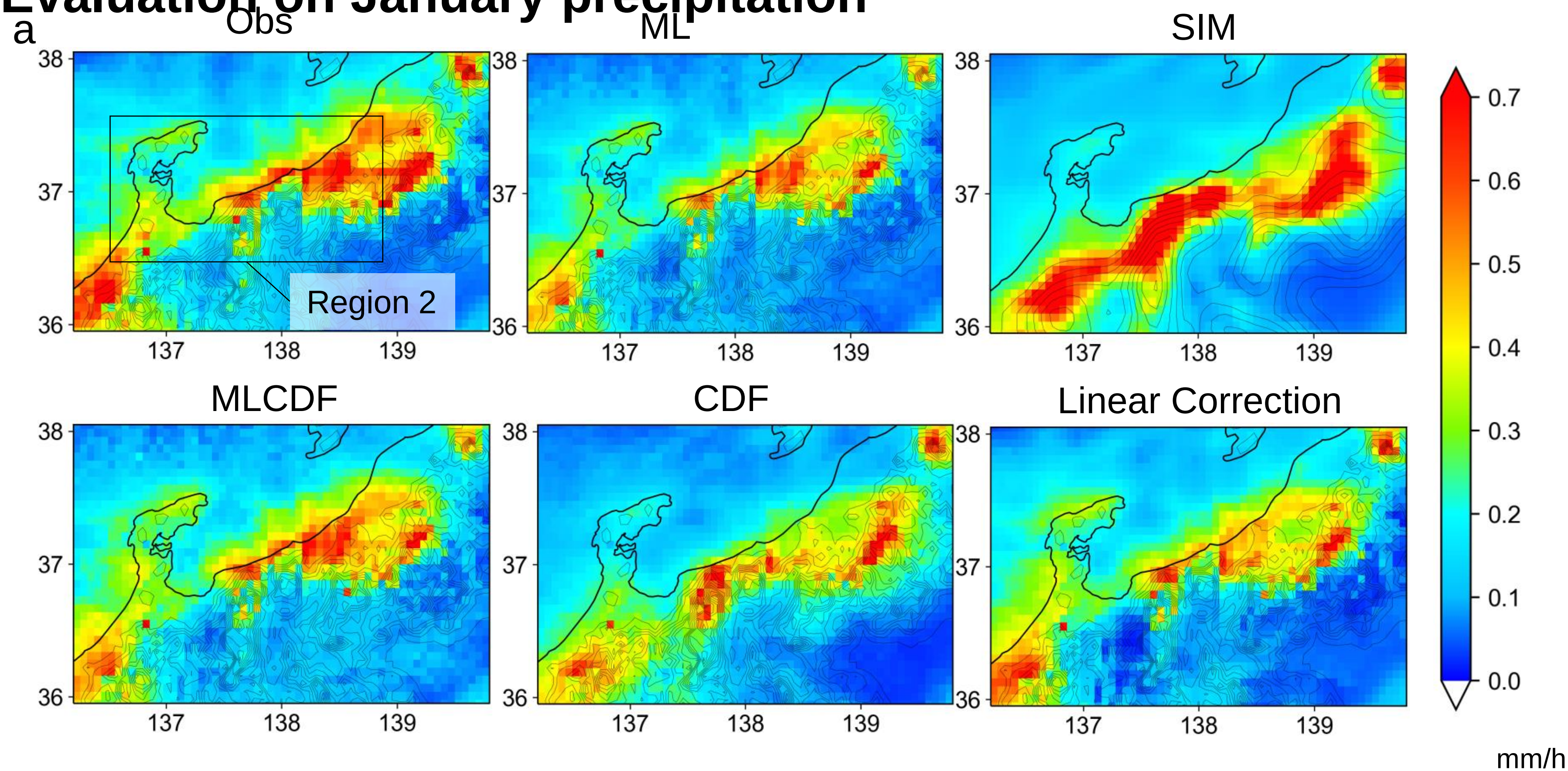
Test data : January 2015 (Typical precipitation distribution)

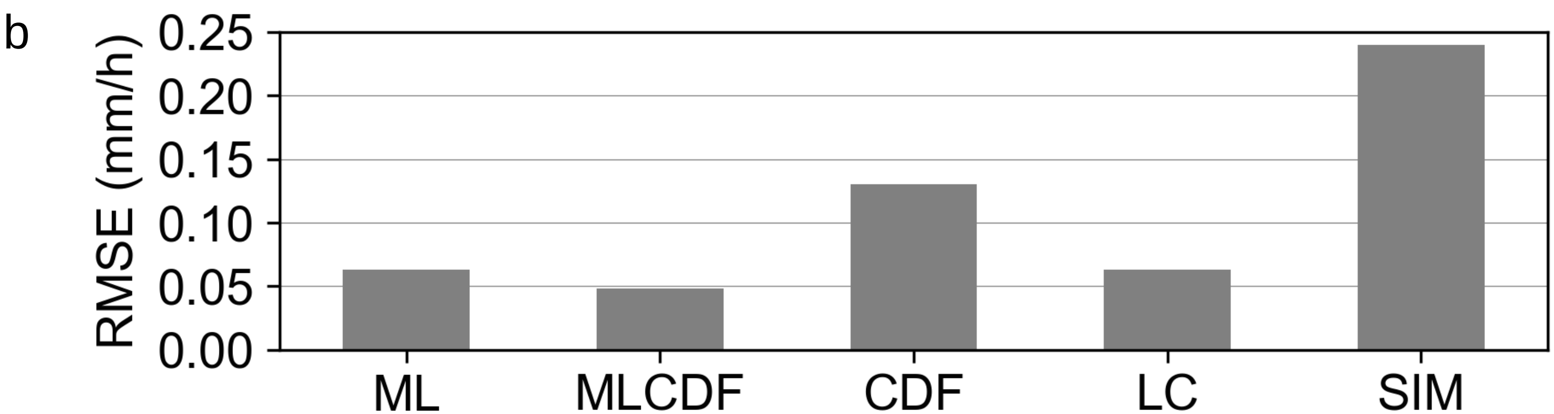


The **classifier** (regression model) is produced by using **the pairs of feature vectors** (simulated precipitation distribution) **and the supervisory signal** (observed precipitation) at each grid.

The precipitation at each grid is predicted using the classifier

Evaluation on January precipitation

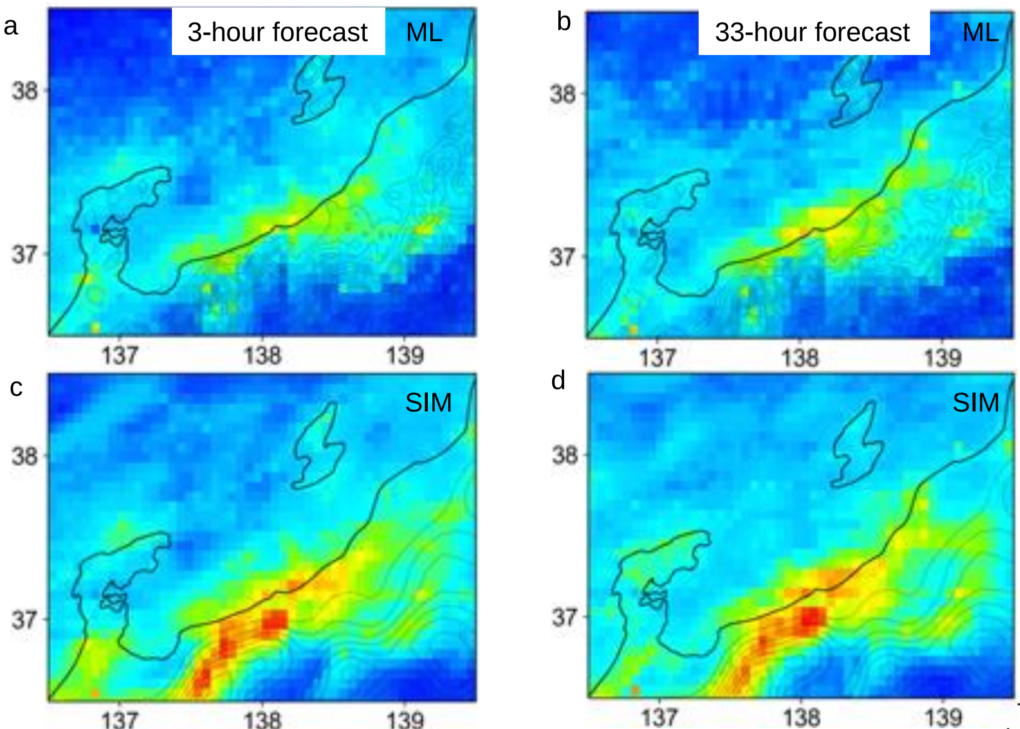


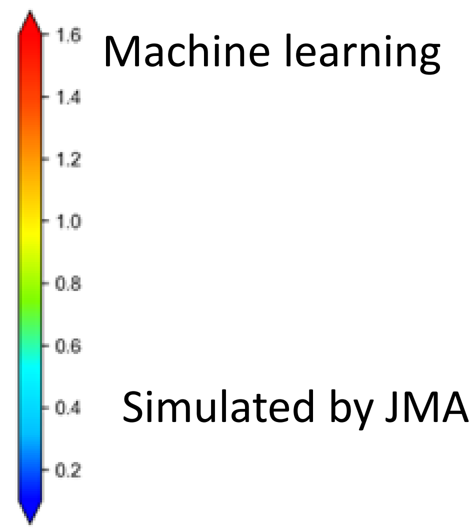


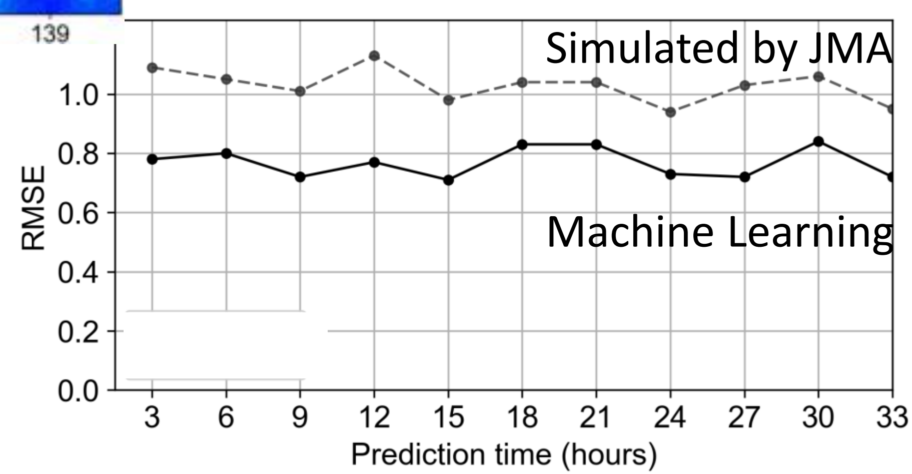
Yoshikane and Yoshimura, submitted.

Improvement in forecasted precipitation

RMSE in hourly precipitation

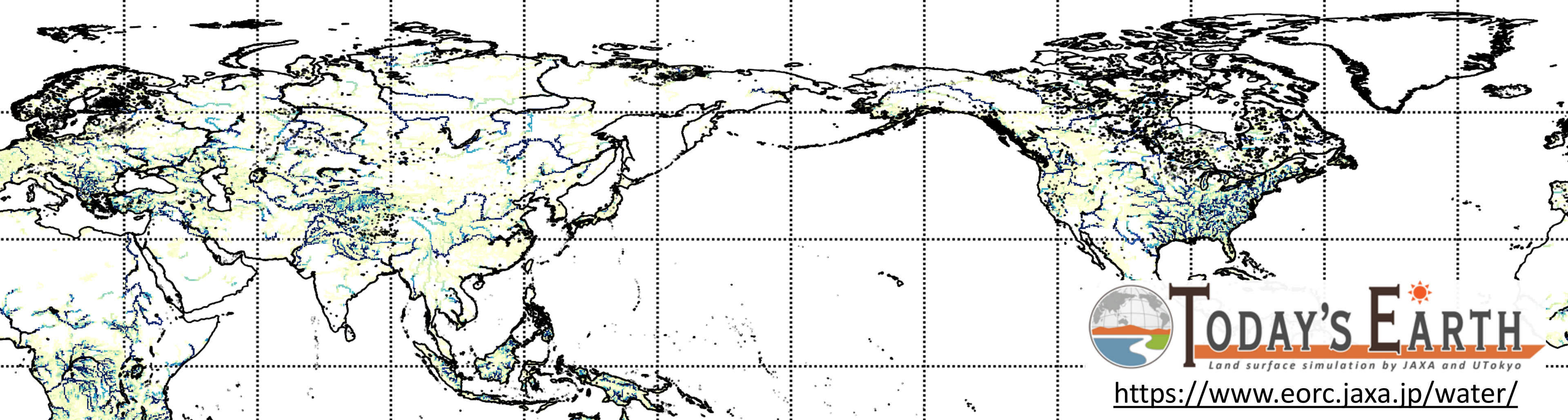






Summary

- We developed *Today's Earth*, or *TE*, a simulation system that provides integrated estimates of physical quantities related to the water cycle on land (e.g., soil moisture content, river flows, evapotranspiration, and many others).
- *Today's Earth* utilizes the land surface simulation technology of the University of Tokyo and the satellite data analysis technology of JAXA/EORC, respectively, and enables us to continuously monitor global land conditions through the internet.
- In the Japanese region in particular, we have established a system to distribute real-time prediction with a resolution of 1/60° grid (about 1 km grid) to the public. It is called *TE-Japan*. Global version (*TE-Global*) has 1/4° grid (about 25km grid).
- We tested the performance of *TE-Japan* for some extreme events. In the case of Typhoon Hagibis in 2019, at 129 of the 142 sites where breaches were reported, the system predicted a once-in-200 years flood level (defined as an alert) for an average of 32.3 hours prior to the event.
- The false alarm rate was around 70% to 80 % throughout the period. This predictive information is being considered for use in a variety of fields, such as the distribution of disaster prevention information in the domestic media and public municipal offices.
- Fusion of *TE* and SAR makes the inundation area estimate better.
- *TE-Japan’*s prediction has been used by NIED’s ”One-stop System”



https://www.eorc.jaxa.jp/water/

Thank you!

If any question/comment, please send keiyoshi08@gmail.com

JAXA EORC 東京大学 生産技術研究所 Institute of Industrial Science, The University of Tokyo

Proposal

1. To port the regional version(s) of Today's Earth System for some region (South east Asia? India?) to Google Earth Engine.

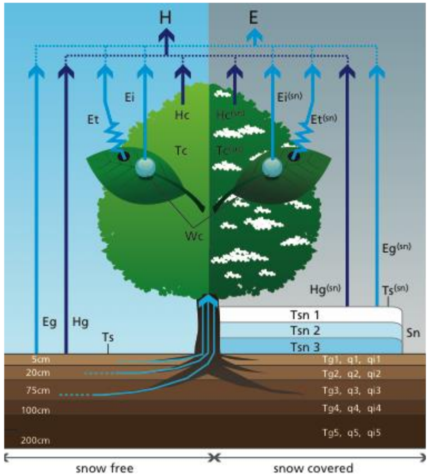
2. To make high-resolution global real time inundation map using multiple L-band/X-band SARs

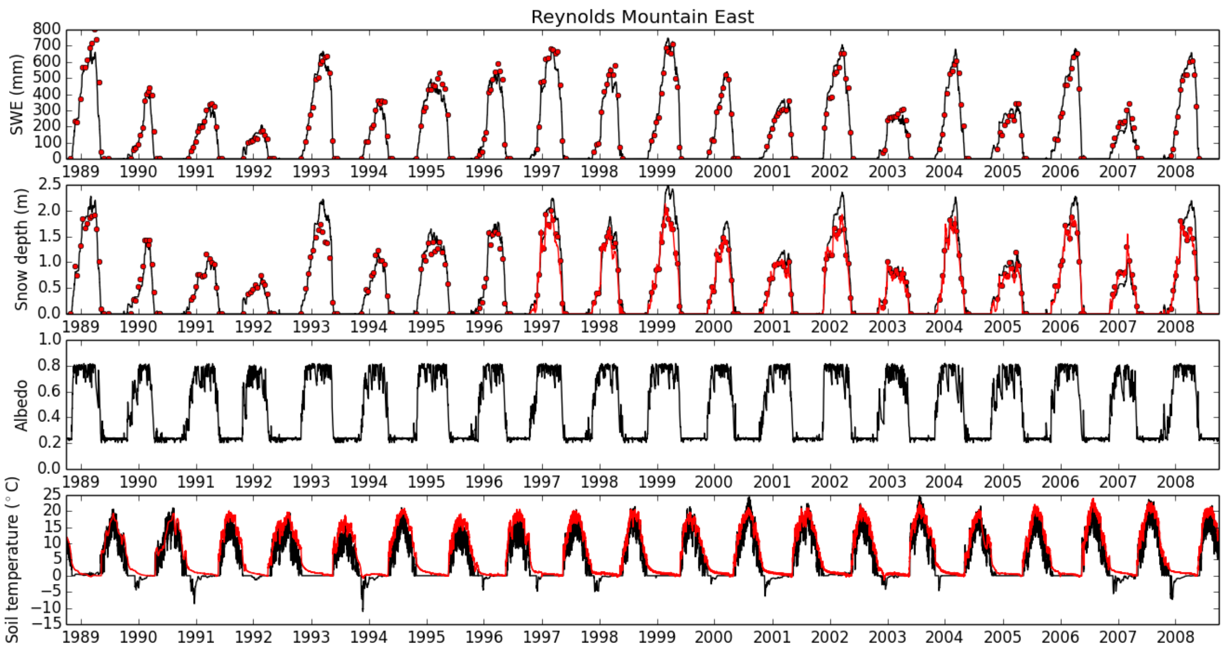
3. To make 1-km global precipitation realtime/forecast using AI s& NWP-precip & GSMaP, Gestational satellites, etc.

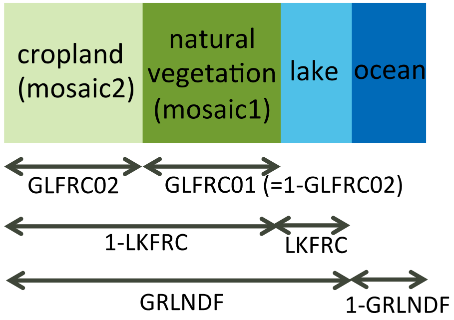
Land Surface Model MATSIRO

Takata et al., 2003
Nitta et al., 2014;2016;2020

- MATSIRO is a land model of MIROC and NICAM models
- It has been also used for impact assessment studies
- It consists from 6 soil layers (14m in total), 3 snow layers, and a single canopy layer and includes various land physics (e.g. radiation transfer, bulk coefficient, snow, runoff, soil property…) and a tile scheme
- The performance has been evaluated through MIP studies







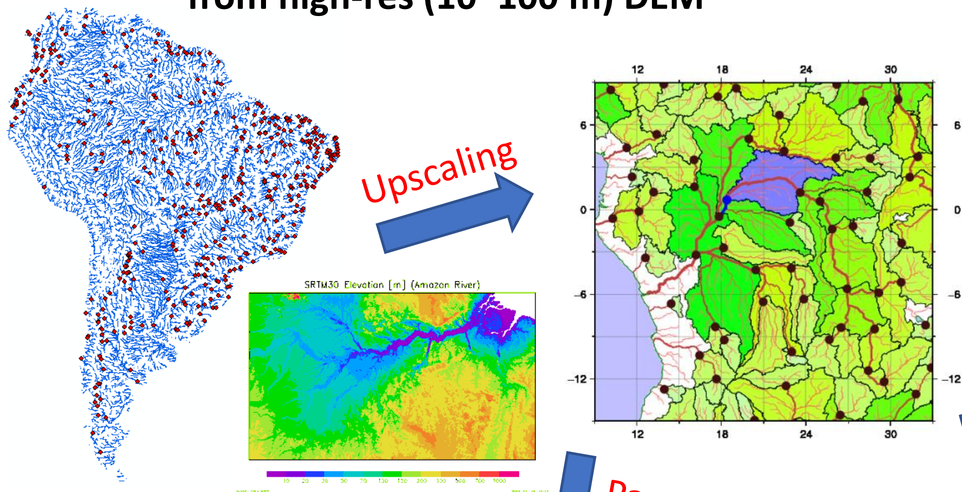
Red: observation Black: simulation

Courtesy of Dr. Essery

Yamazaki et al., 2013; 2014; etc.

River Inundation model CaMa-Flood

Abstract sub-grid topographic characteristic from high-res (10~100 m) DEM

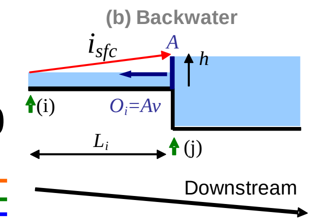


Diffusive Wave Equation
Depending on water level, "backwater" occurs.

$$\frac{1}{g}\frac{\partial v}{\partial t}+\frac{v}{g}\frac{\partial v}{\partial x}+\frac{\partial h}{\partial x}+i_0-i_f=0$$

Kinematic
Diffusive
Dynamic

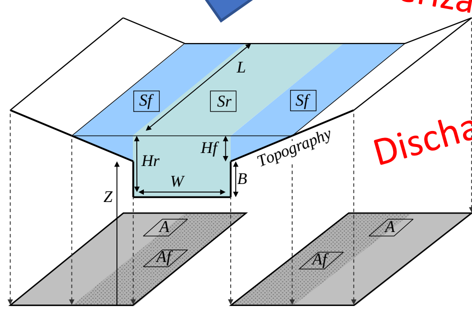
St. Venant Momentum Equation



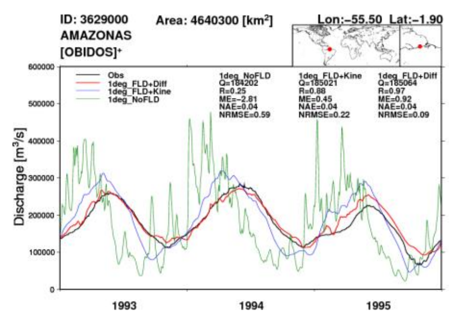
In addition to river discharge, water level altitude and inundation area is simulated.
→ comparable to satellite-based estimates.

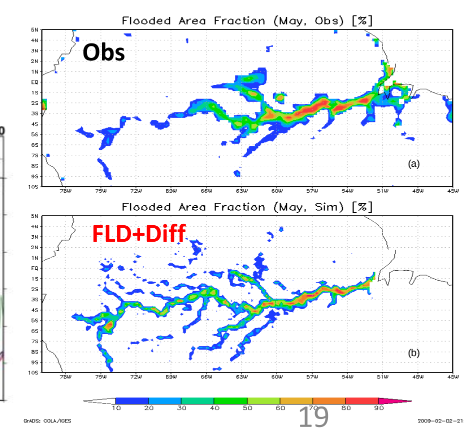
Parameterization

Parameter	Channel Elevation	Z
	Channel Length	L
	Channel Width	W
	Embankment Height	B
	Catchment Area	A
	Floodplain Elevation Profile	*f(Topography)*
Variables	River Storage	S_r
	Floodplain Storage	S_f
	River Water Depth	H_r
	Floodplain Depth	H_f
	Inundated Area	A_f



Discharge, w-level, inundation are predicted.



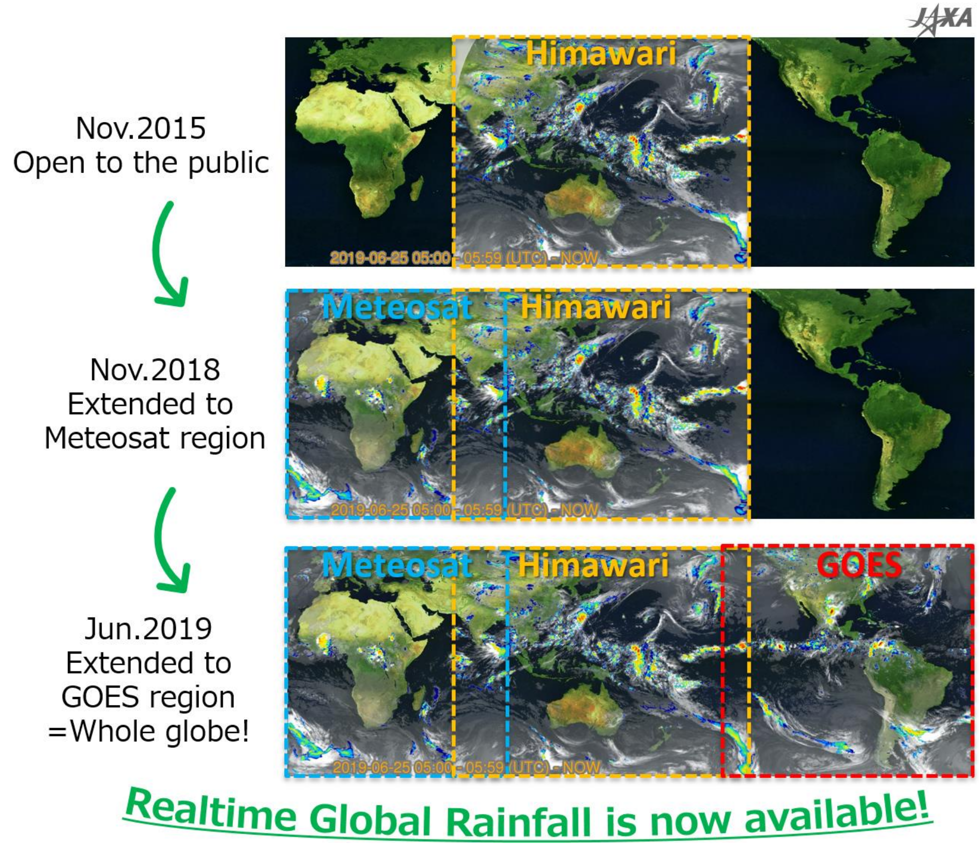


Each grid represents basin shape with sub-grid topographic parameters. River water depth and inundation area is explicitly calculated.

Realtime ver. of GSMaP is now available

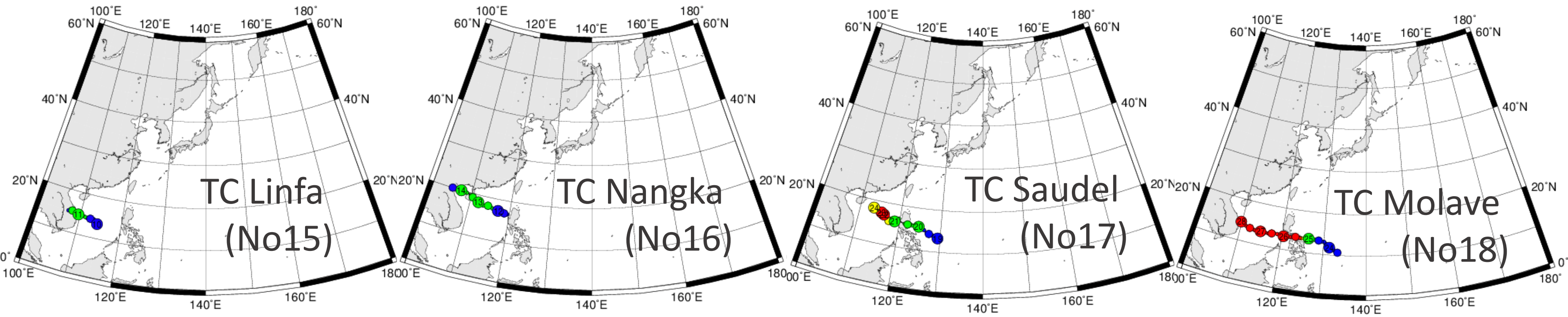
JAXA has operated the "JAXA Realtime Rainfall Watch (GSMaP_NOW)" website from November 2015, which provides "realtime" rainfall information within GEO-satellite Himawari domain. The domain of the JAXA Realtime Rainfall Watch had been extended to GEO-satellite Meteosat region since November 2018.

From Jul 1, 2019, the domain of JAXA Realtime Rainfall Watch (GSMaP_NOW) has been extended to the whole globe by utilizing GEO-satellite GOES, which means that we can use global rainfall data in realtime.



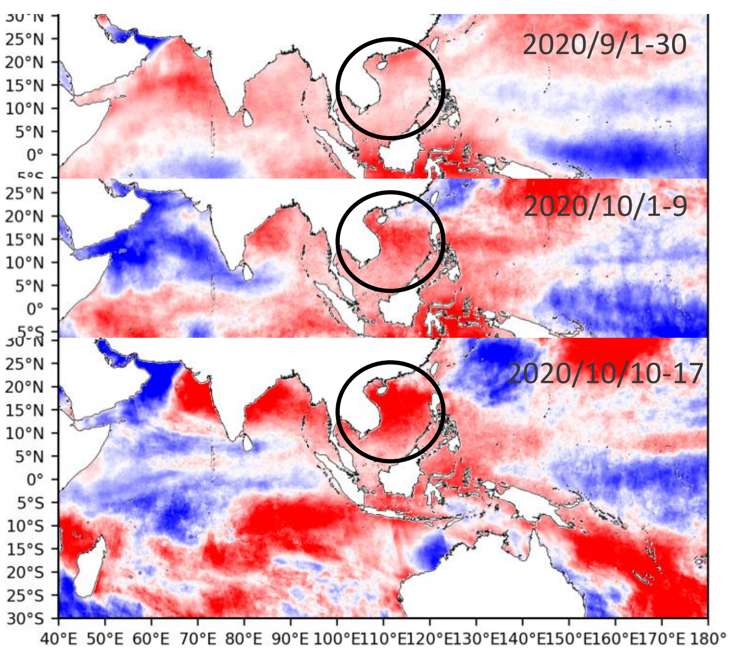
Visit GSMaP_NOW !! → https://sharaku.eorc.jaxa.jp/GSMaP_NOW/index.htm

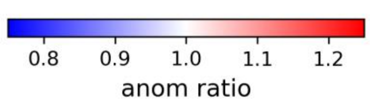
Example of global view: TCs Linfa, Nangka, Saudel, Molave…



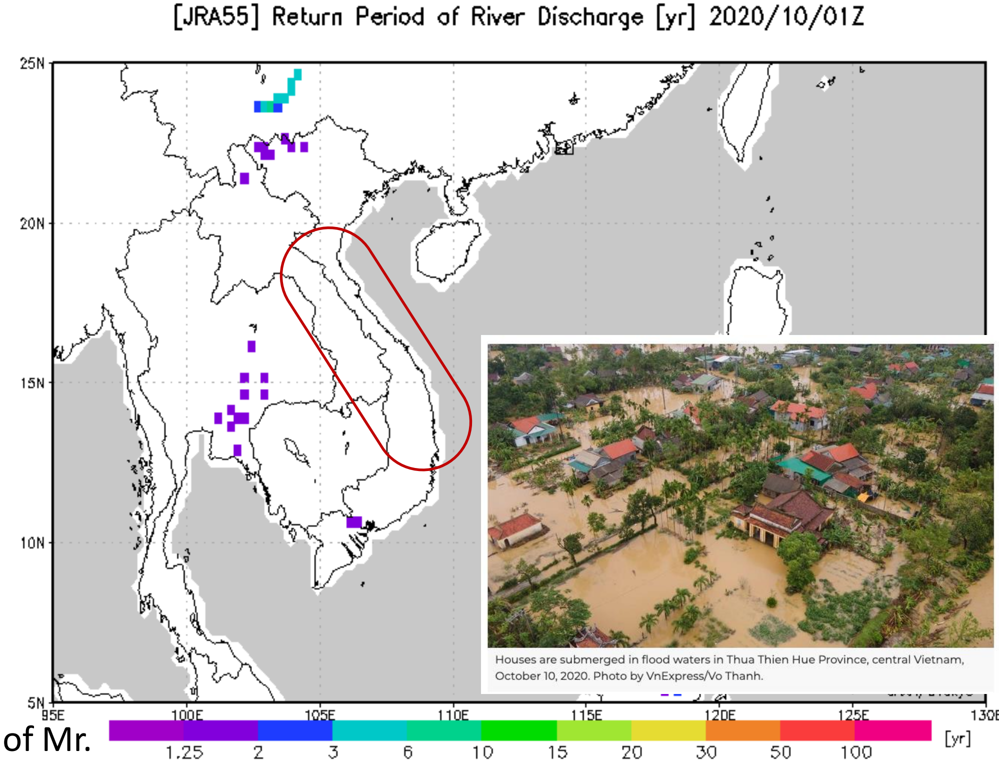
http://agora.ex.nii.ac.jp/digital-typhoon/

AMSR2/GCOM-W TWV anomaly ratio



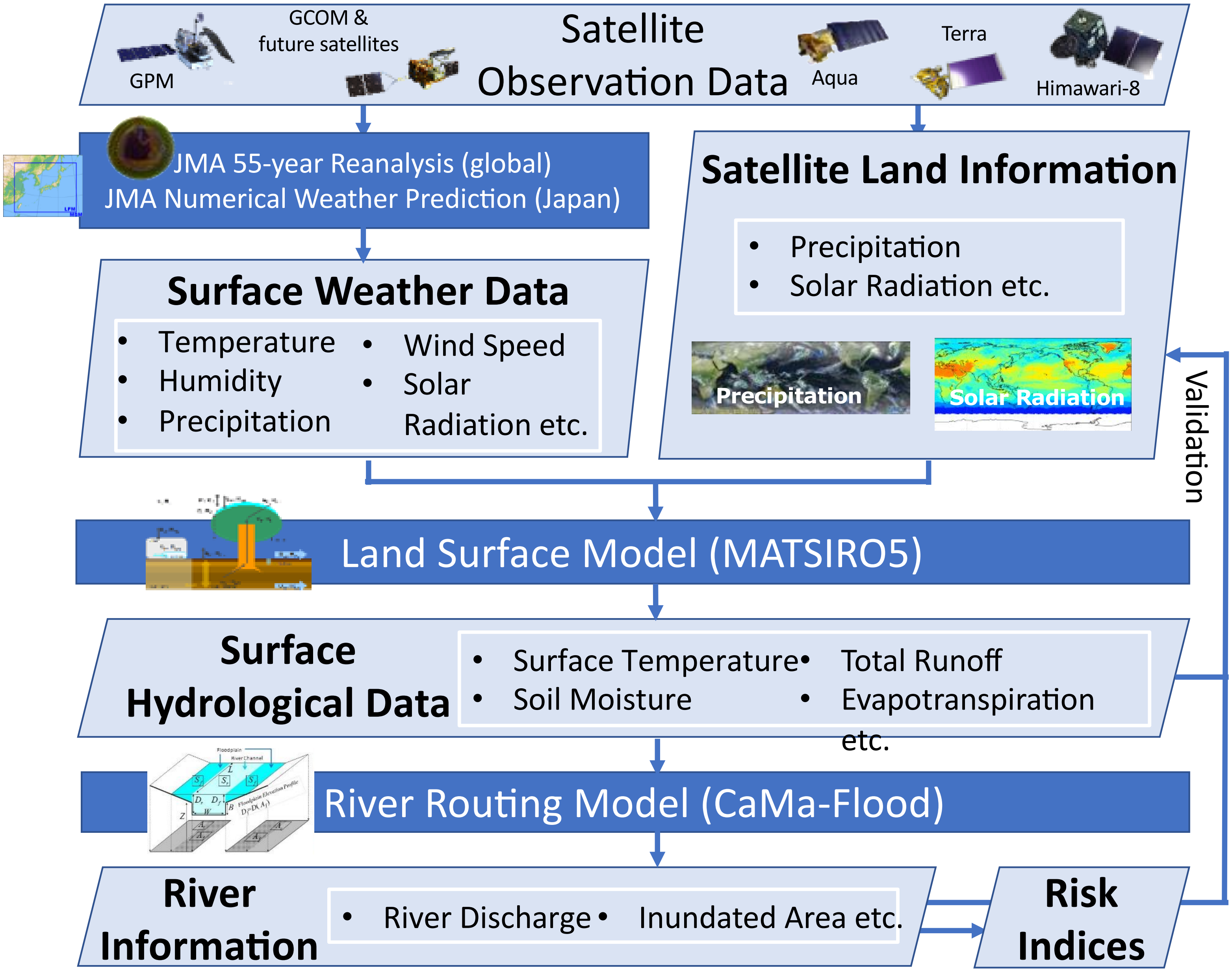


Courtesy of Mr. Ohara (JAXA)



Courtesy of Mr. Yamamoto (JAXA)

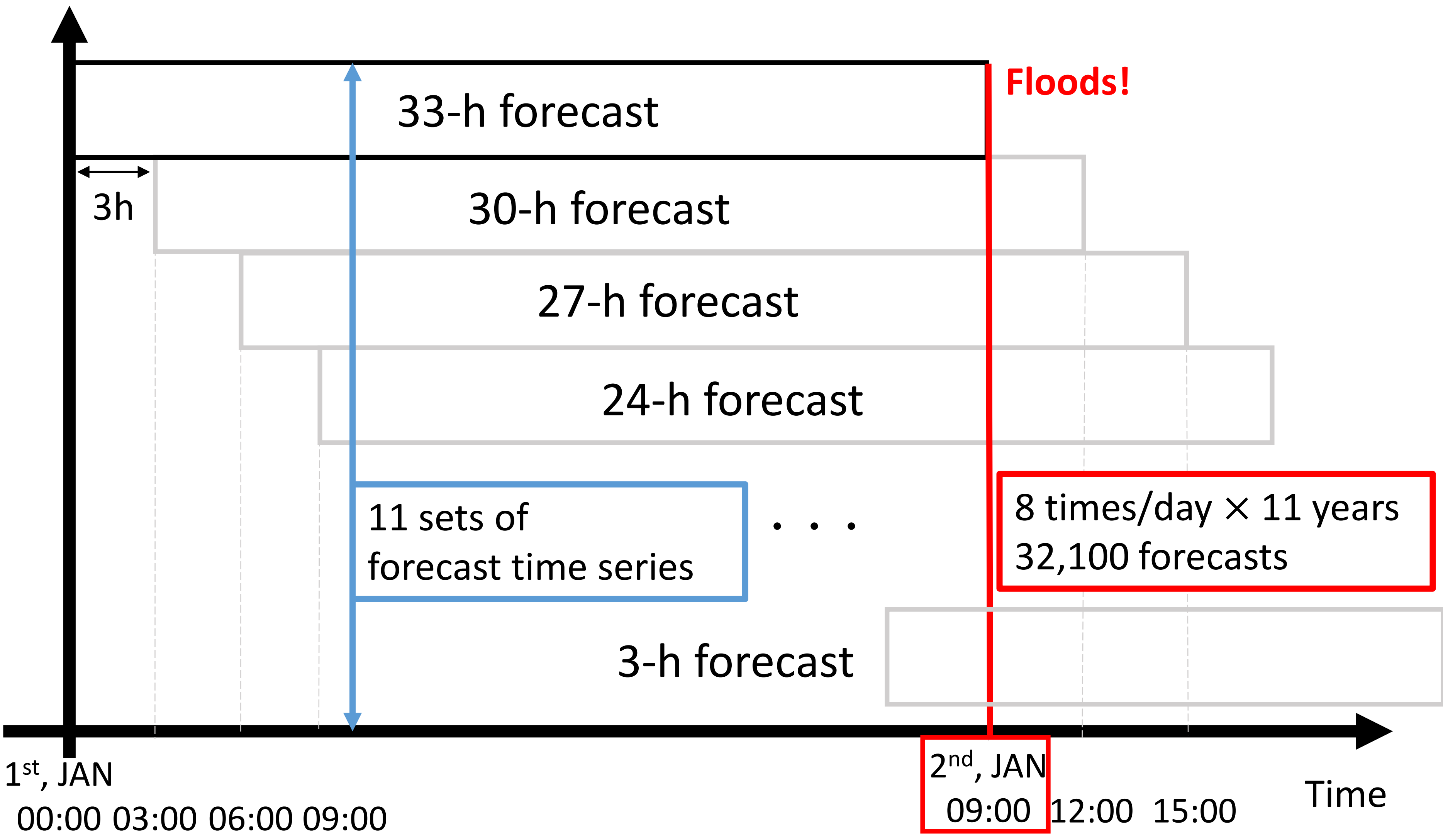
TE Data flow


GCOM &
future satellites
GPM
Satellite
Observation Data
Aqua
Terra
Himawari-8
JMA 55-year Reanalysis (global)
JMA Numerical Weather Prediction (Japan)
Satellite Land Information
• Precipitation
• Solar Radiation etc.
Precipitation
Solar Radiation
Surface Weather Data
• Temperature
• Humidity
• Precipitation
• Wind Speed
• Solar Radiation etc.
Validation
Land Surface Model (MATSIRO5)
Surface Hydrological Data
• Surface Temperature
• Soil Moisture
• Total Runoff
• Evapotranspiration etc.
River Routing Model (CaMa-Flood)
River Information
• River Discharge
• Inundated Area etc.
Risk Indices

Validation for 11-year hindcasted runs

Forecasts: 33-h lead time, Issued every 3hours

Assessing the accuracy in each lead time from short to long



Forecast ability for high flows

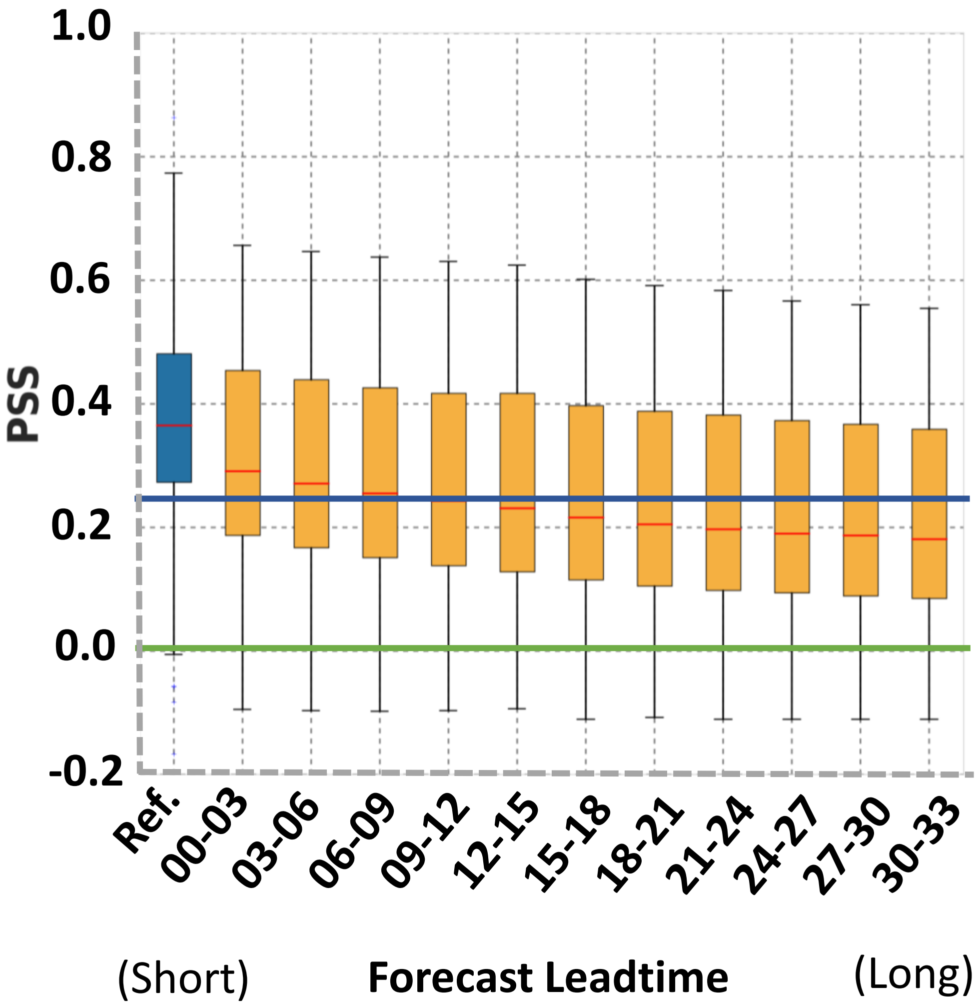
$$\mathrm{PSS} = \frac{Hit}{Hit + Miss} - \frac{FA}{FA + CN}$$

Hit Rate (1 − Miss Rate)

False Alarm Rate

[2007 - 2017]

N = 849 stations



Reference Values

[e.g., Addor et al., 2011; Alfieri et al., 2013]

- PSS ≥ 0.00 : **Have a Predictability**

Forecasts 33-h before:
Having a positive PSS at more than ***90%*** out of 849 stations.

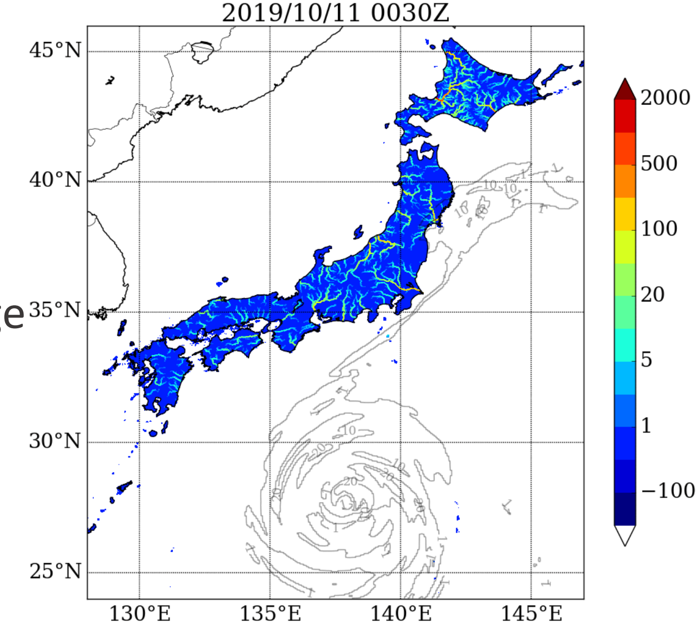
Forecasts 12-h before:
Having PSS > 0.25 at more than ***50%*** out of 849 stations.

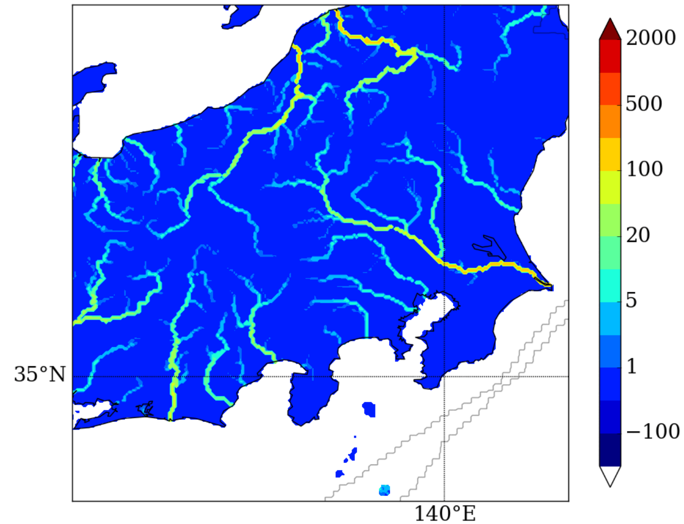
Ishitsuka et al., in prep.

2019's case

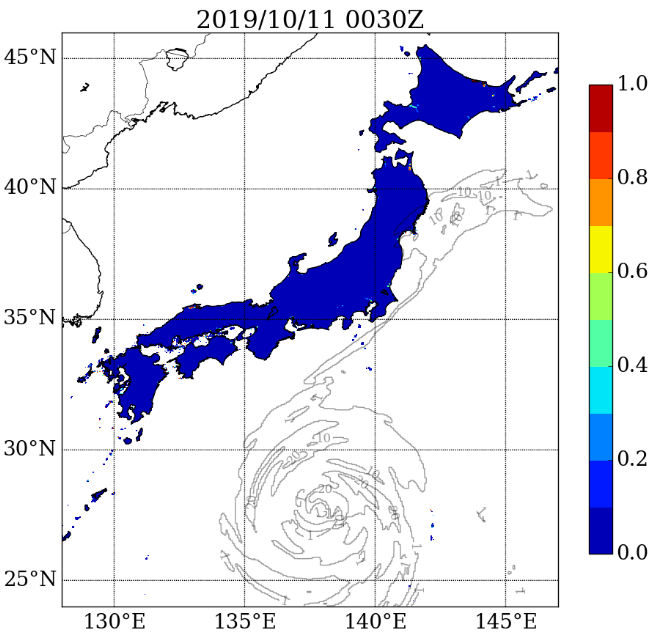
Prediction from 11 Oct 9JST by TE-Japan (1km-ver.)

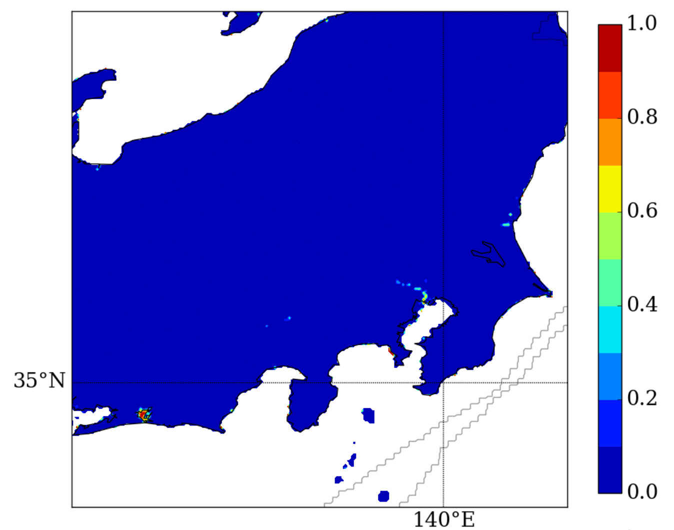
River Discharge [m^3/s]





Inundated area [fraction]





Courtesy of K. Hibino