Forecasting Severe Local Storms with advanced DA and Ensemble
— Beyond Weather Forecast —

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This presentation is supported by WMO, IITM, KAKENHI “23K03498”.

Contents

- Achievement of current NWP for a historical disaster in Japan, 1959
- Deterministic forecasts for local severe storms with advanced DA
- Probabilistic forecasts with a large ensemble DA
- Impact-based forecast

Typhoon Vera (1959)

Life: 21 - 27, Sep 1959

Landfall: 18 JST, 26 Sep 1959

Central pressure:

895 hPa (minimum)

929 hPa (at landfall)

-> 2nd record in statistics from 1951

Storm surge: 389 cm at Nagoya Port

-> 1st record

Damage:

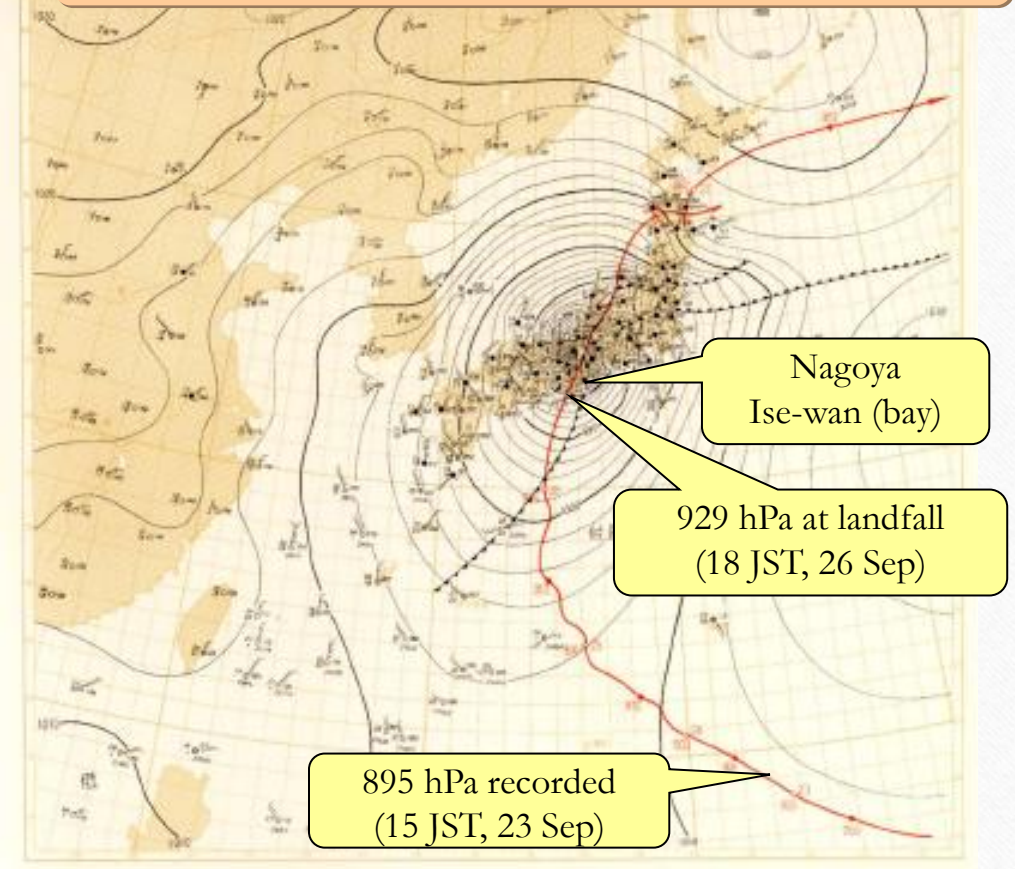
Fatalities and missing: 5,098

-> 1st record for meteorological disaster

Totally destroyed houses: 40,838

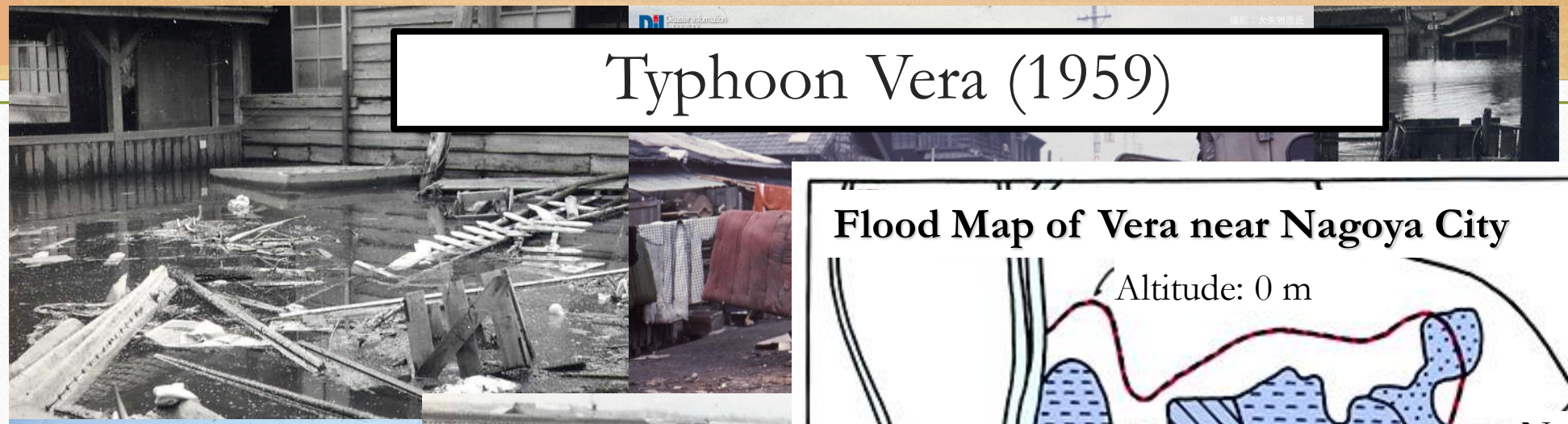
Flooded houses: 363,611

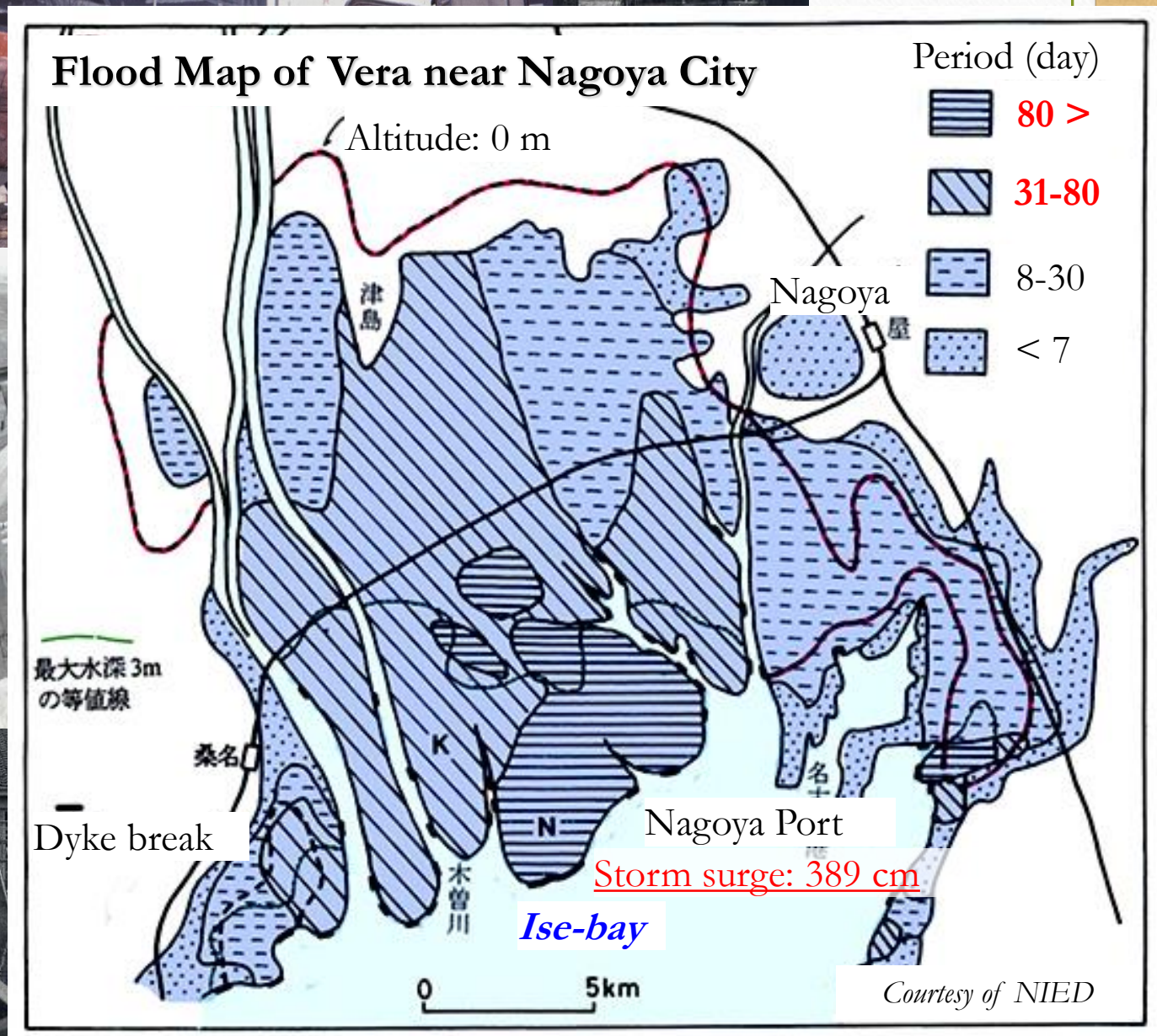
Surface Weather Map （21 JST 26 Sep 1959）



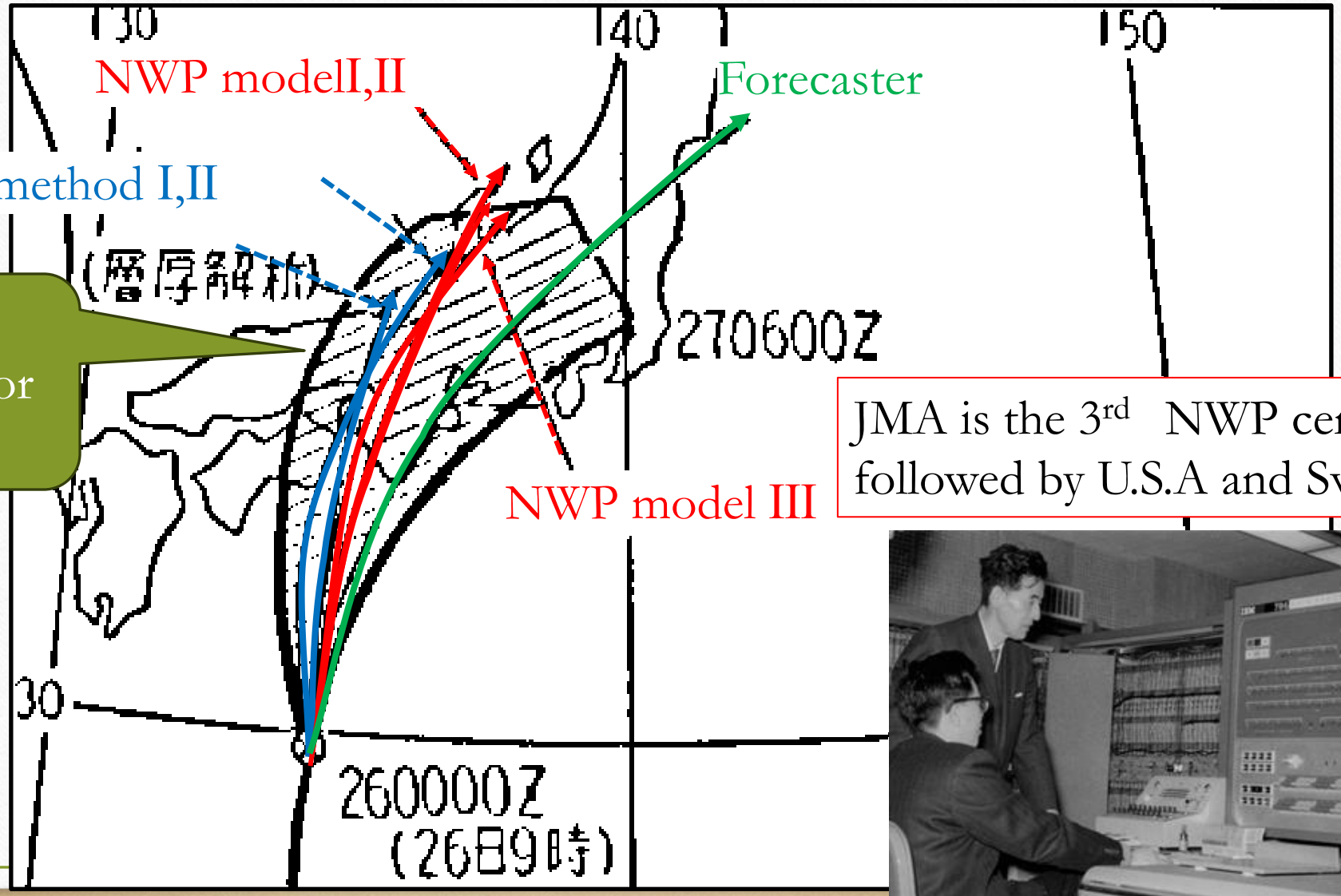
Vera or "Ise-wan typhoon" is referred to as the most disastrous typhoon in Japan due to the record-breaking storm surge.

Typhoon Vera (1959)





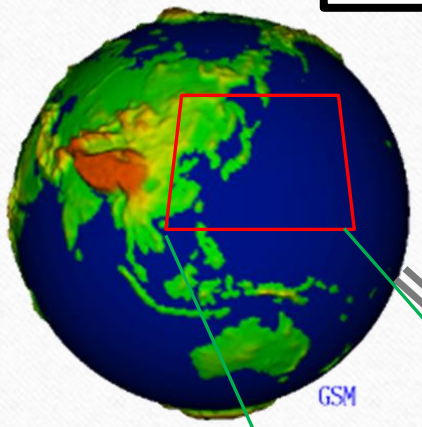
Operational Forecast for Vera in 1959



Forecast on typhoon direction for 24-h

JMA is the 3rd NWP center followed by U.S.A and Sweden.

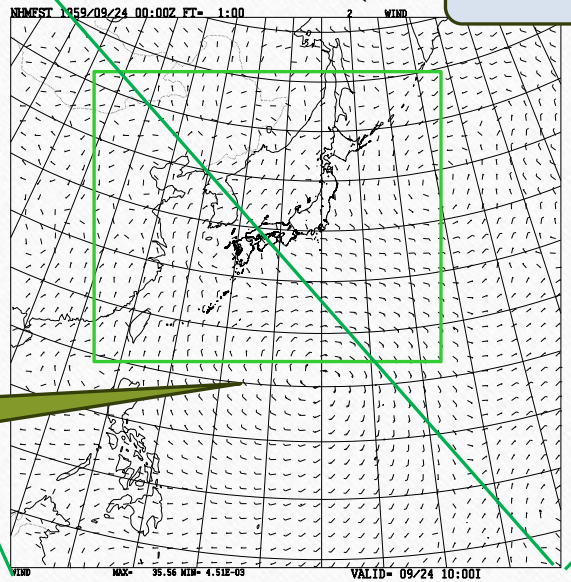
Weather forecast for Vera with Current NWP



JMA Global Reanalysis (60km)
JRA-55

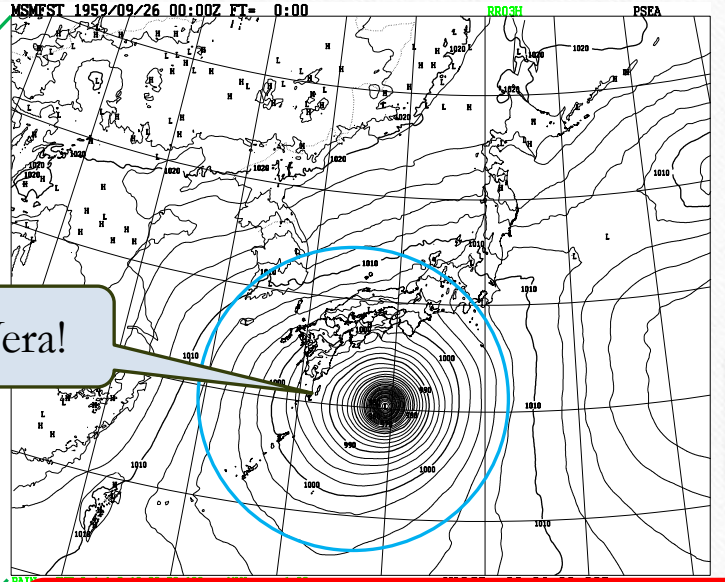
Downscaling

NHM (20kr



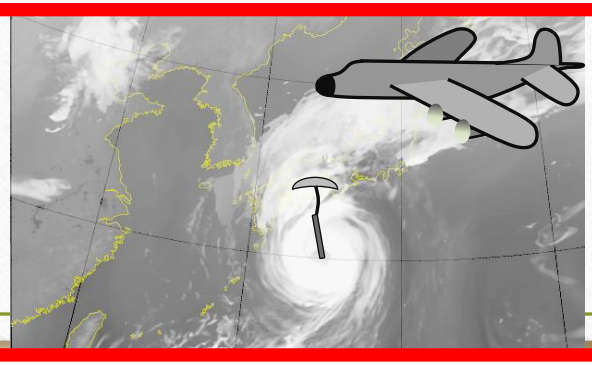
Weak Typhoon Simulated

Operational 4D-Var (2008-2020)



Succeed to simulate Vera!

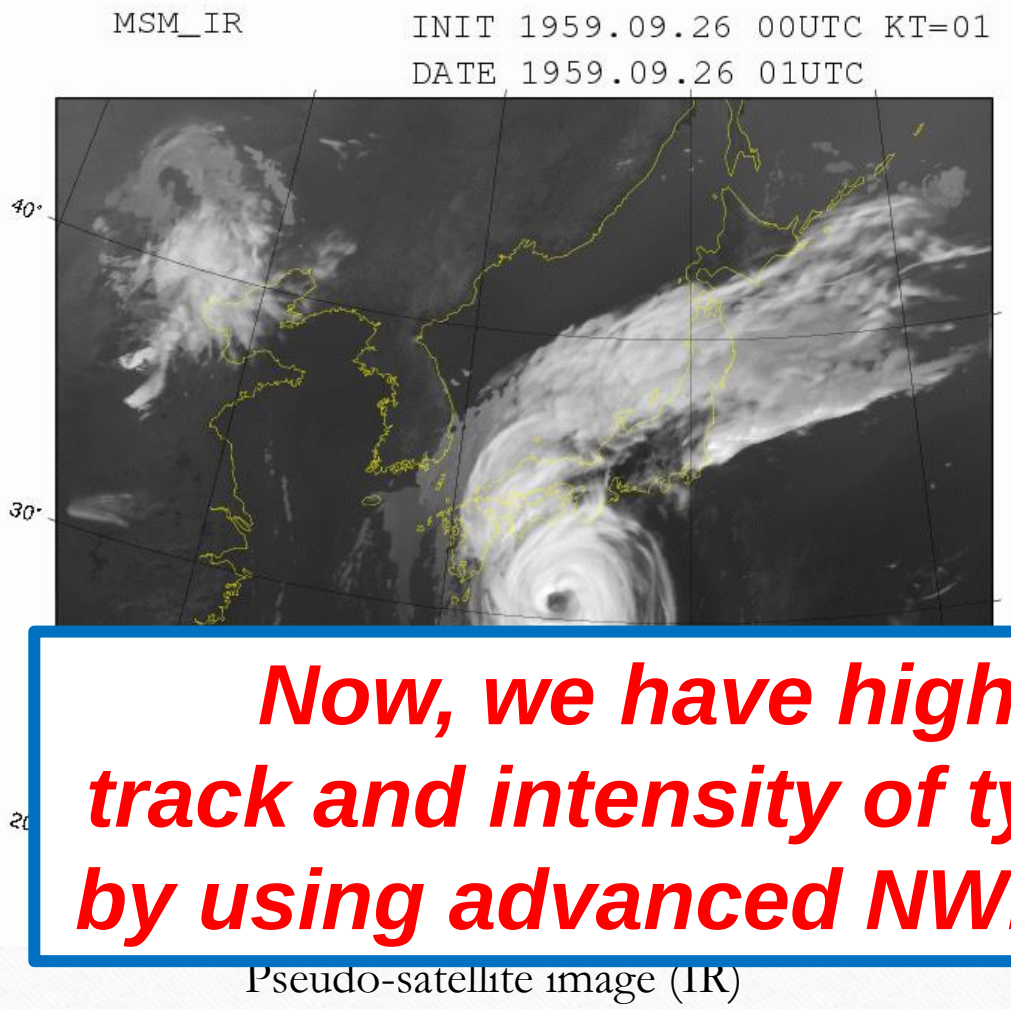
Dropsonde by U.S. air force
in the eye of typhoon



Upper Sounding, SHIP, SYNOP

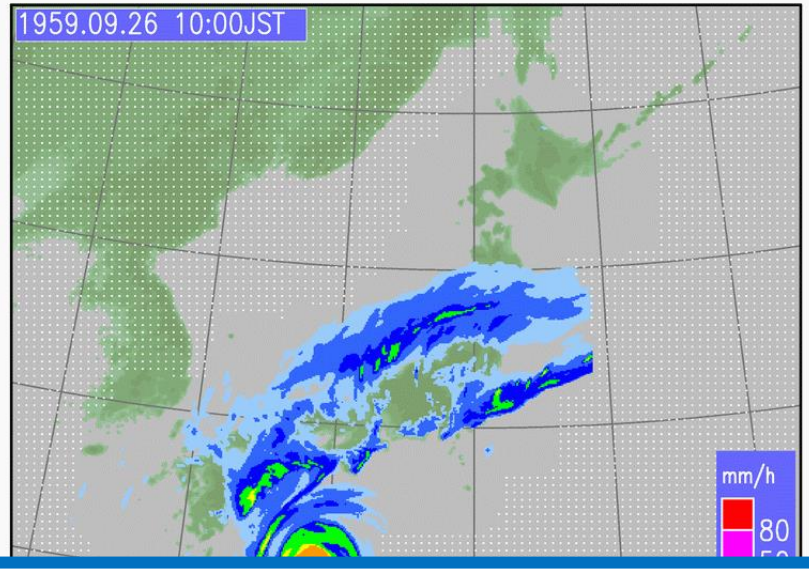
Prediction of Typhoon Vera

JMA's first satellite, GMS was launched in 1977



Pseudo-satellite image (IR)

S-band radar on Mt. Fuji started operation in 1964

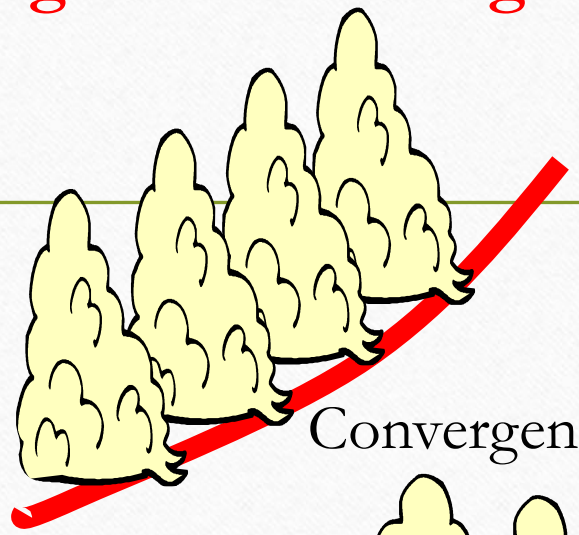


Now, we have high ability to predict track and intensity of typhoons and weather by using advanced NWP systems and HPCs!

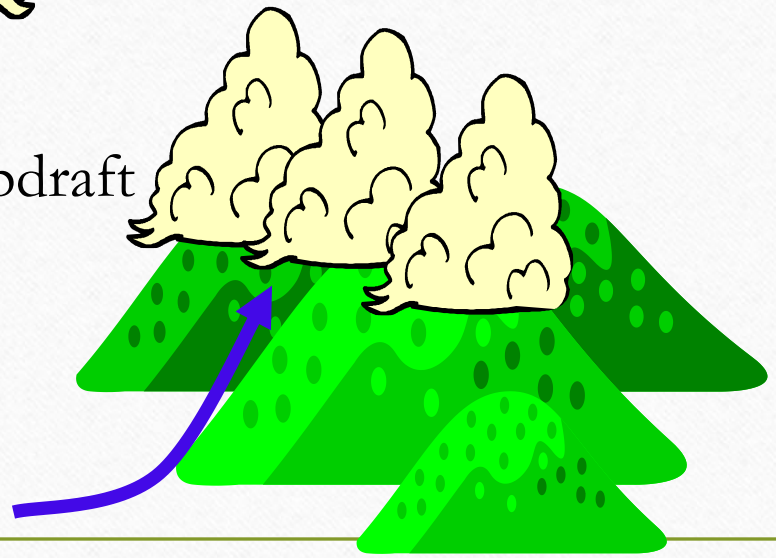
Kawabata et al., 2012, *JMSJ*

Predicting Local Storms

Large-scale forcings

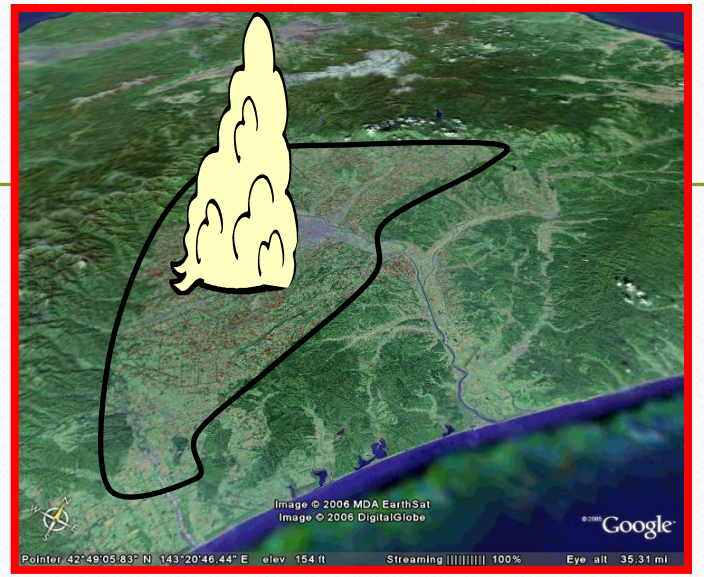


Convergence by fronts



Orographic updraft

Small-scale forcings



Local Storms

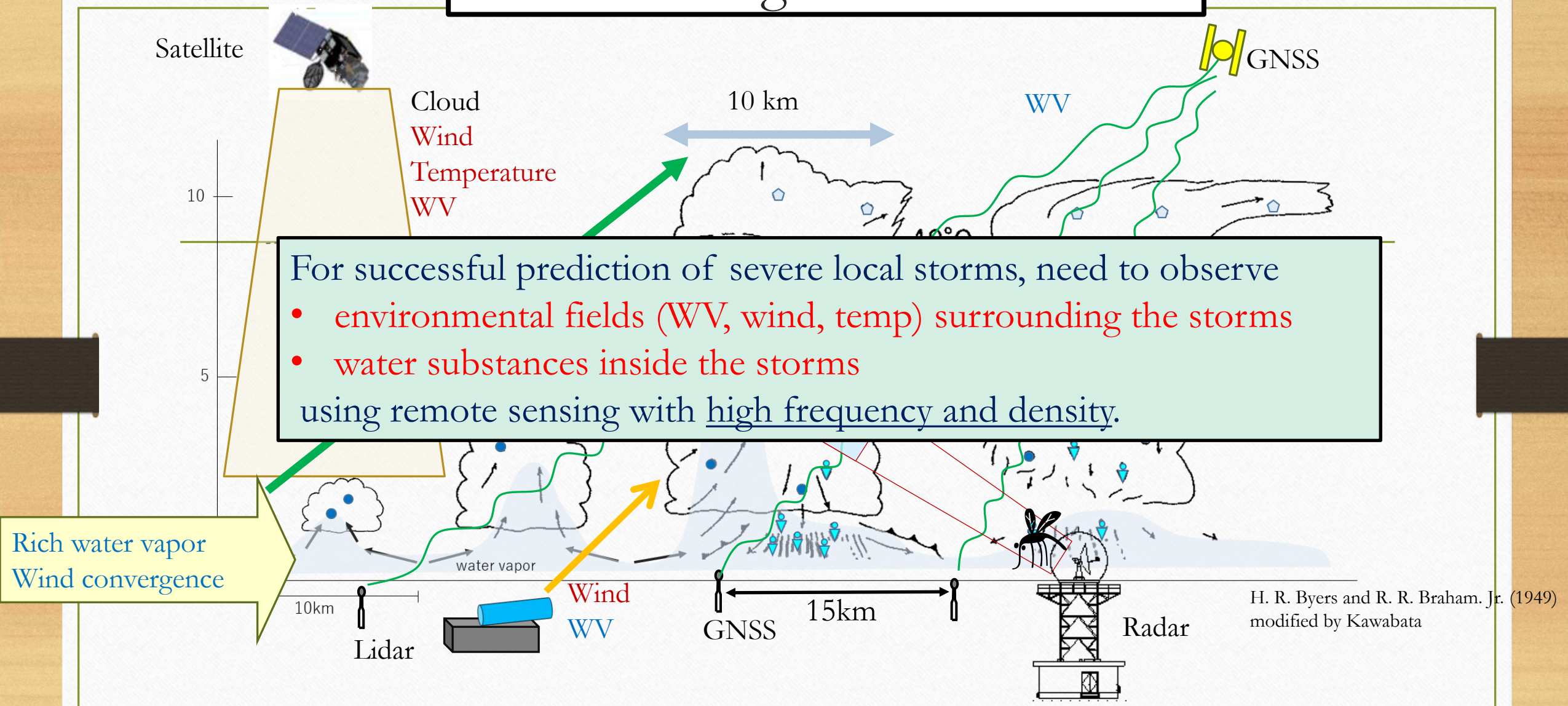
Small scale in space

Large variation in time

Hard to predict!

Deterministic

Observing Local Storms



Two Approaches for Predicting Severe Local Storms

1. Deterministic prediction
   Quantitative prediction detecting when, where, how much
   Limited within 3~5 h due to chaotic behavior of the atmosphere
2. Probabilistic prediction (ensemble)
   Precise probability with less sampling errors!
   Applicable for 24 h

Deterministic

NHM-4DVAR

(Kawabata et al. 2007; 2011; 2013; 2014a, b, 2018a, b)

Model

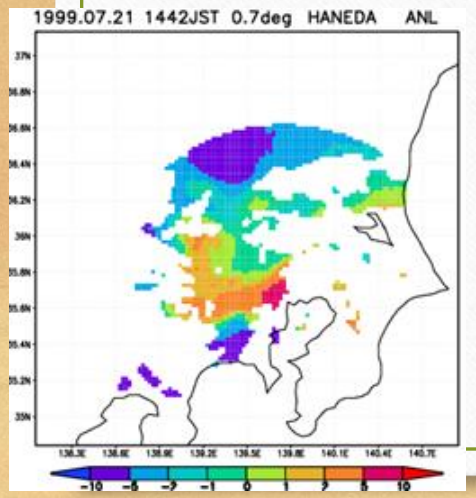
- Forward model: JMANHM with full physics (Former JMA operational meso-scale model)
- Adjoint model: Dynamical core, Cloud microphysical process (warm rain; w/o parameterization)

Observation

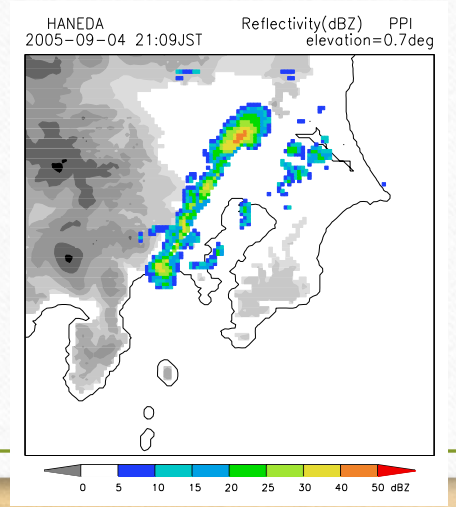
- Doppler radial velocity, radar reflectivity, polarimetric parameters,
  GNSS precipitable water vapor, slant total delay, zenith total delay,
  Doppler wind lidar, RASS, wind profiler, surface wind, surface temperature, surface pressure

Horizontal resolution

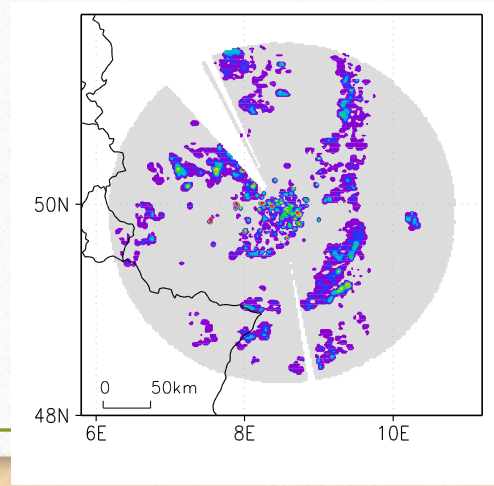
- 2.0 km (0.5 km)



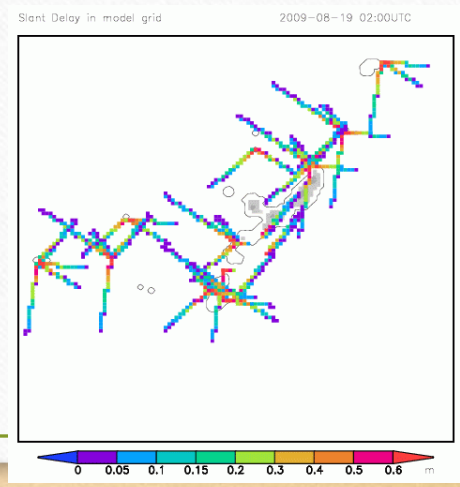
Doppler radial velocity



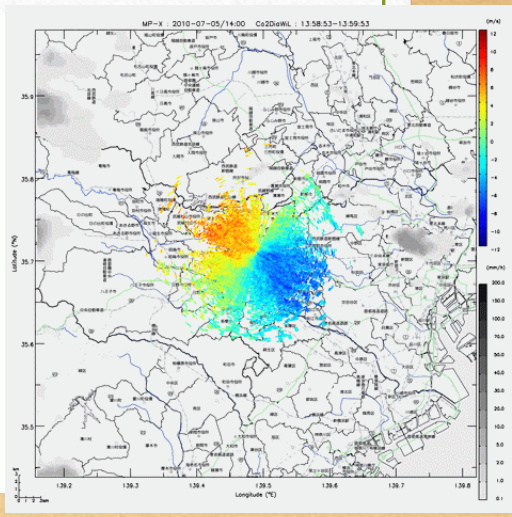
Radar reflectivity



Polarimetric parameters



GNSS slant total delay

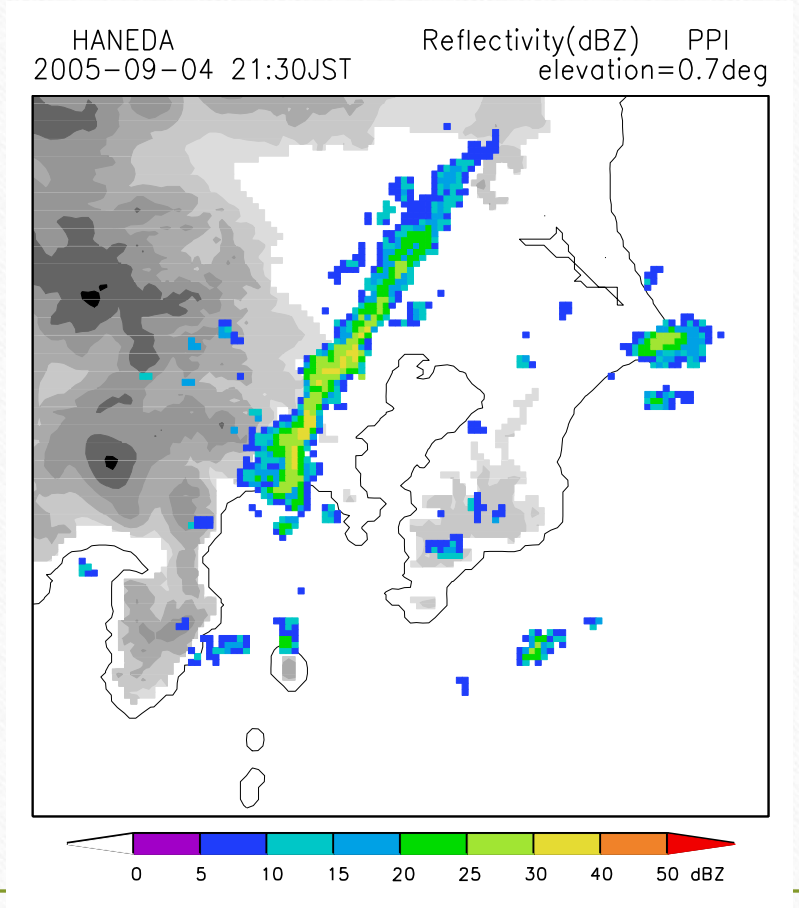


Doppler wind lidar

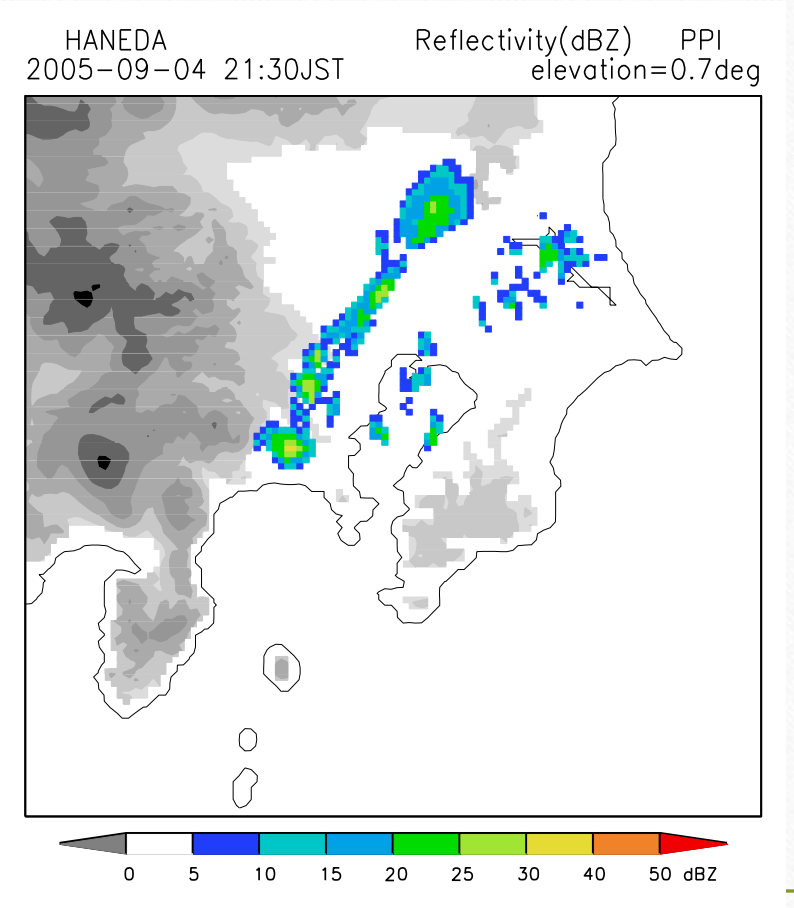
Predicting Linear MCS

Assimilating reflectivity, Doppler radial velocity and PWV

Obs 2059JST



Fcst 2059JST

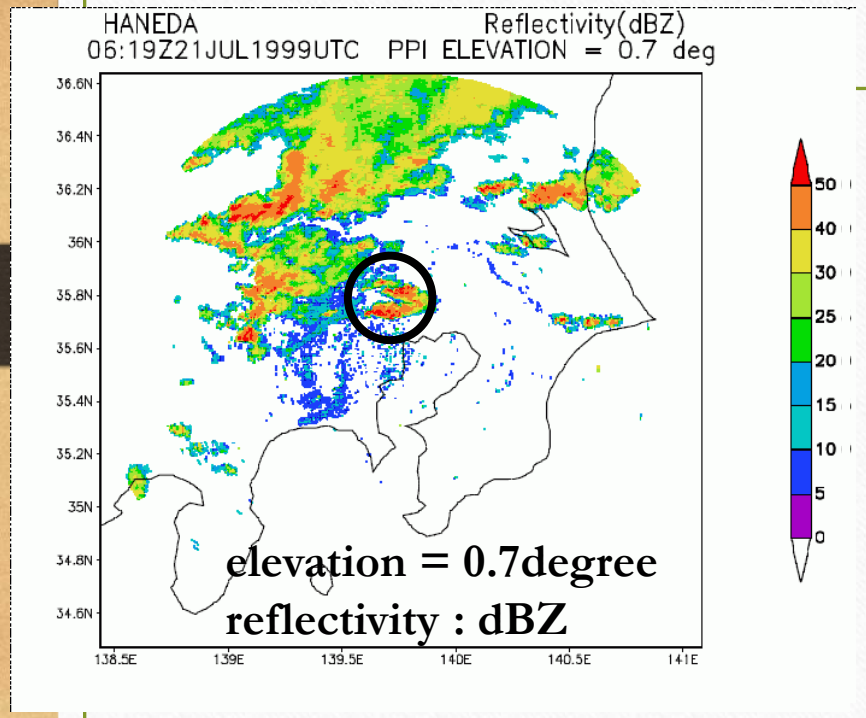


Kawabata et al. (2011)

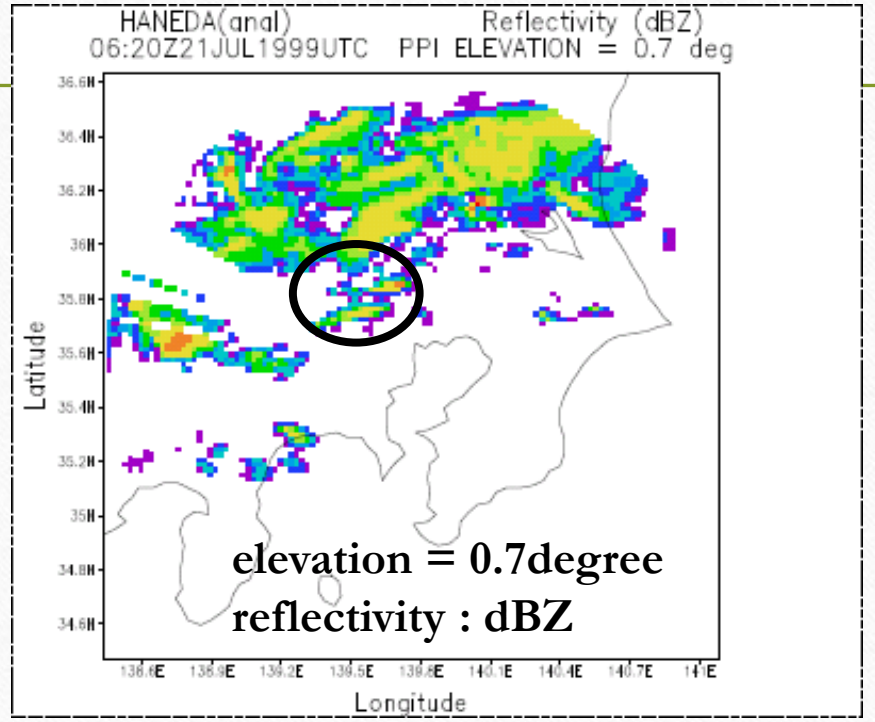
Predicting Cumulonimbus

Assimilating Doppler radial velocity and PWV Kawabata et al. (2007)

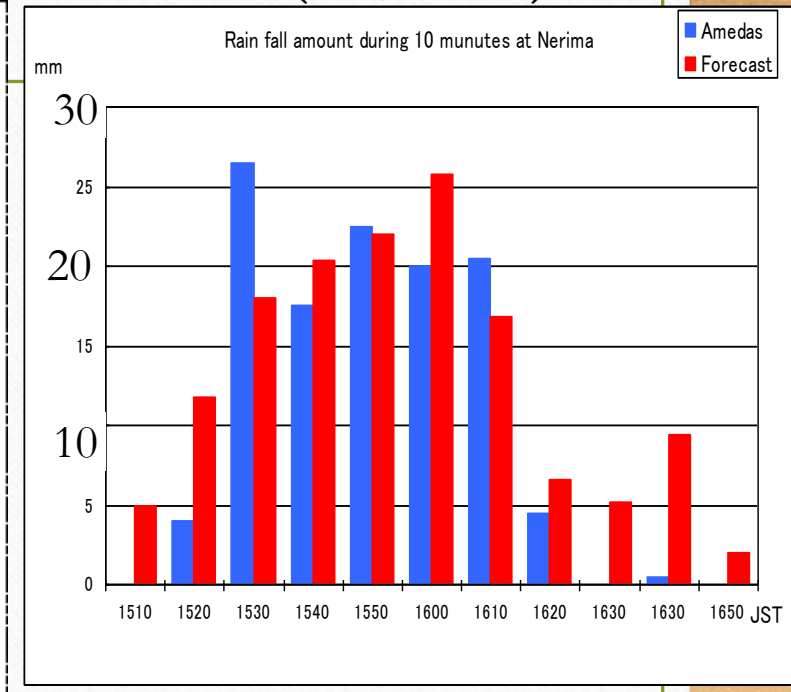
Observation



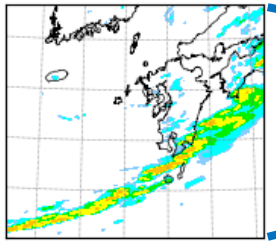
Forecast result



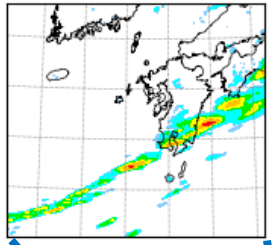
10-min rainfall amount (obs, model)



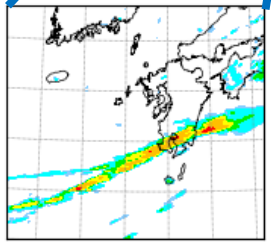
First study to predict an isolated cumulonimbus from the initiation to the end in comparison with observations



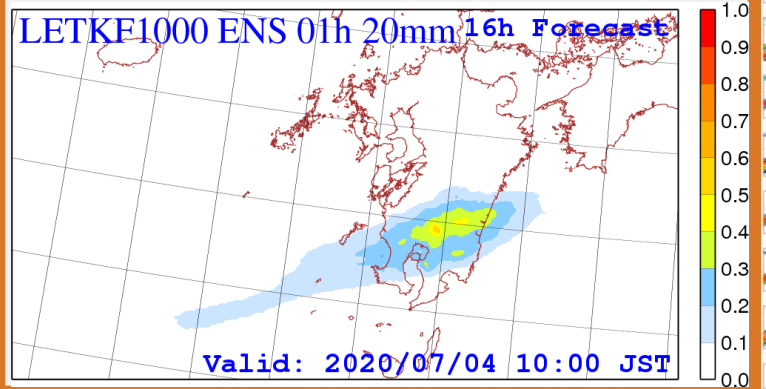
1000 Linear MCSs
initialize by NHM-LETKF
(2 km, 24-h)

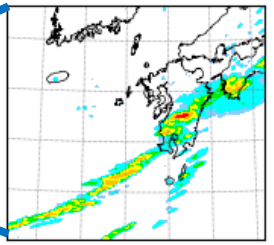


25



Probability Distribution
(> 20mm/1-h)





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Probabilistic Prediction

Radar Observation

Deterministic prediction started with ensemble mean

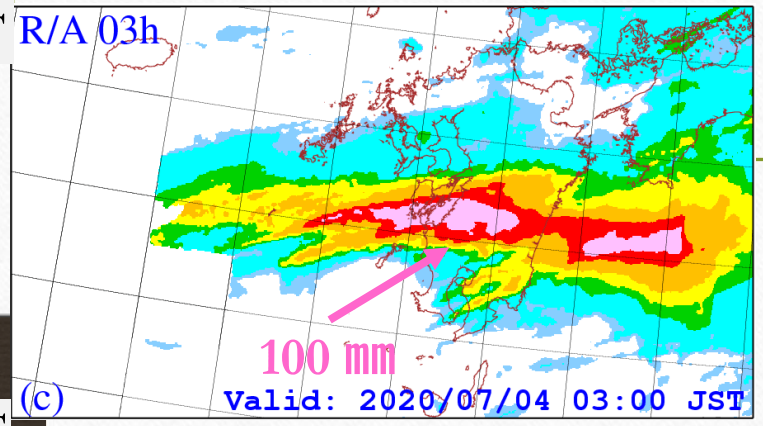
Probabilistic prediction with 1000 members

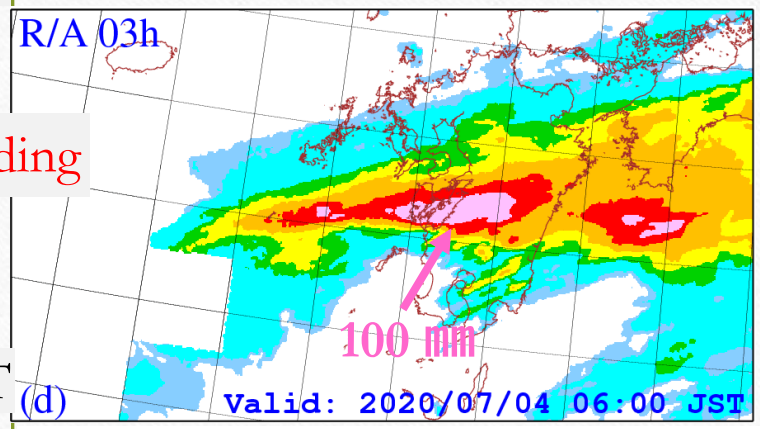
7/4
0 JST

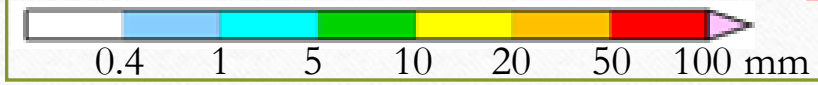
3 JST

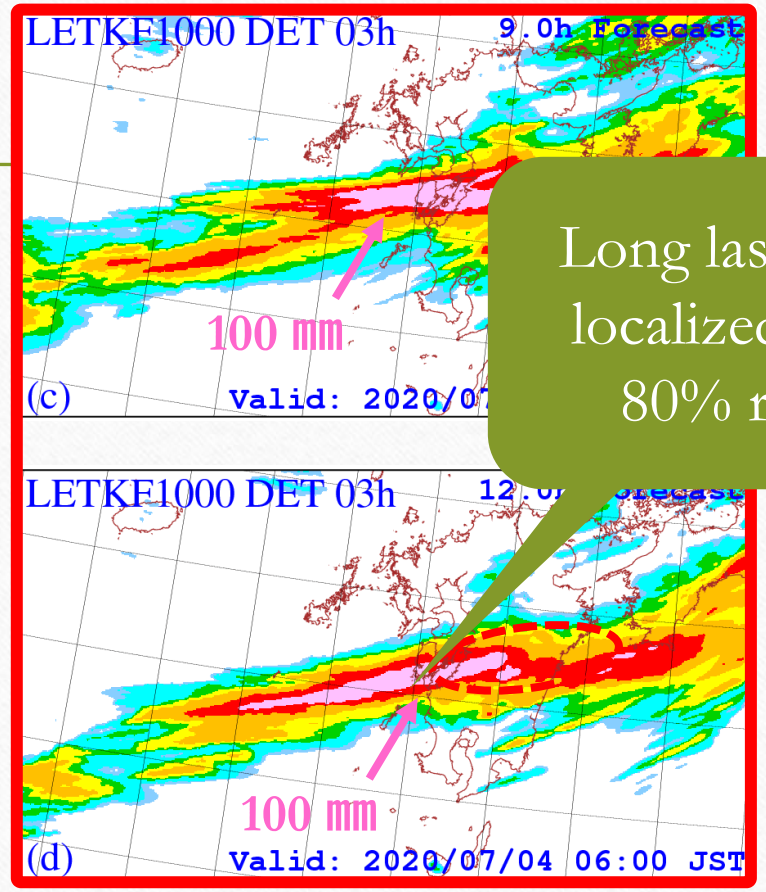
Flooding

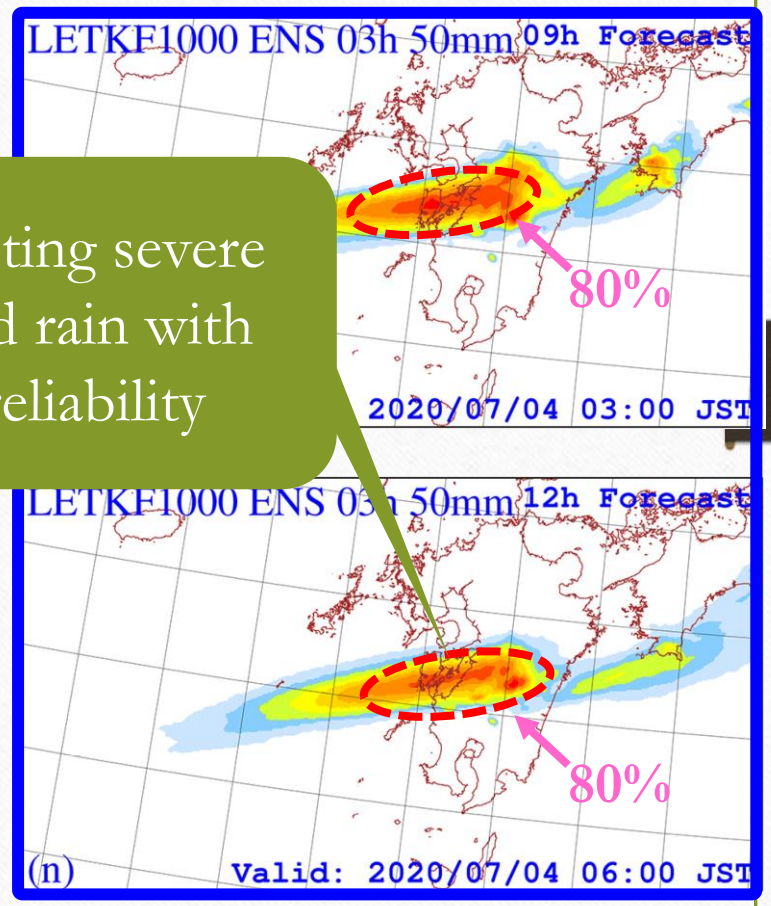
6 JST











Long lasting severe localized rain with 80% reliability

Duc et al. (2021)

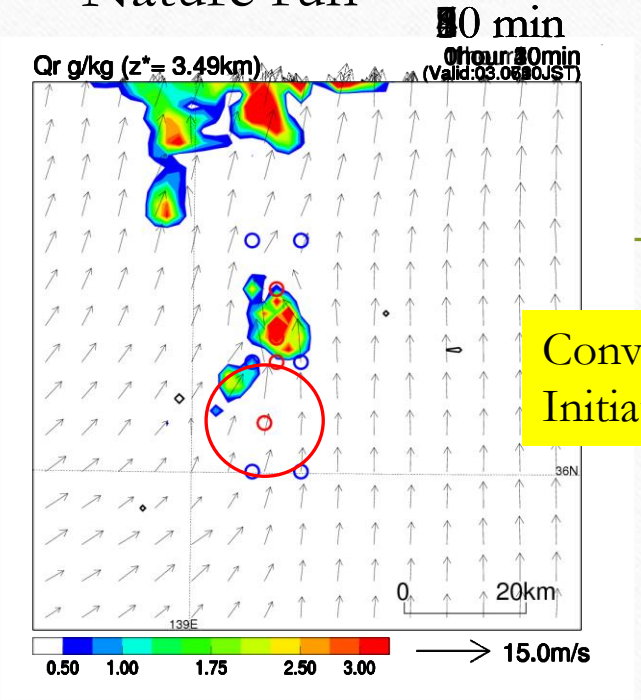
NHM-RPF

Kawabata and Ueno 2020, *MWR*

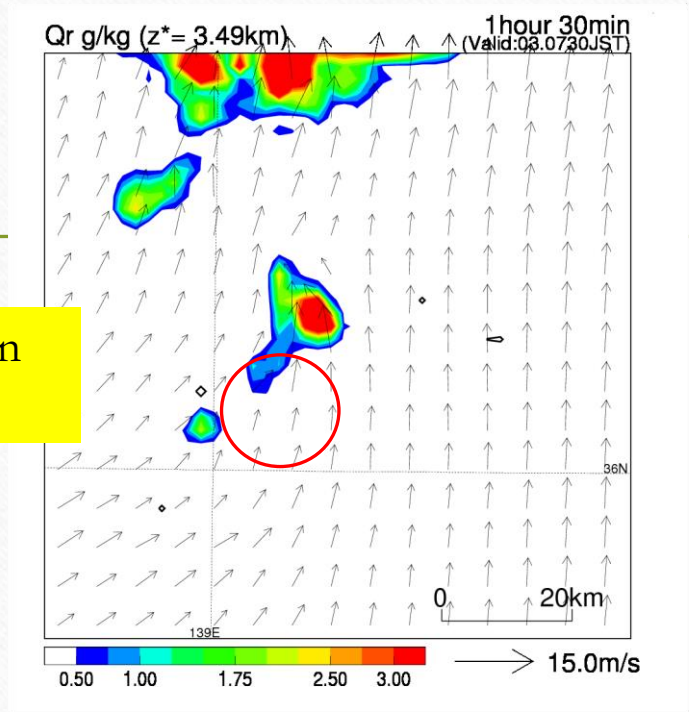
- Particle Filter with nonlinear process and non-Gaussian PDF
- Sampling Importance Resampling (SIR) filter
- JMANHM (Saito et al. 2006; 2007; 2012)
  The JMA mesoscale nonhydrostatic model
  - 2-moment cloud microphysics (3-ice)
  - Deadorff (1980)
  - 2 km
- Observation operators (NHM-4DVAR)
- Adaptive R-Estimator (ARE: Ueno and Nakamura 2016)

Predicting Cumulonimbus

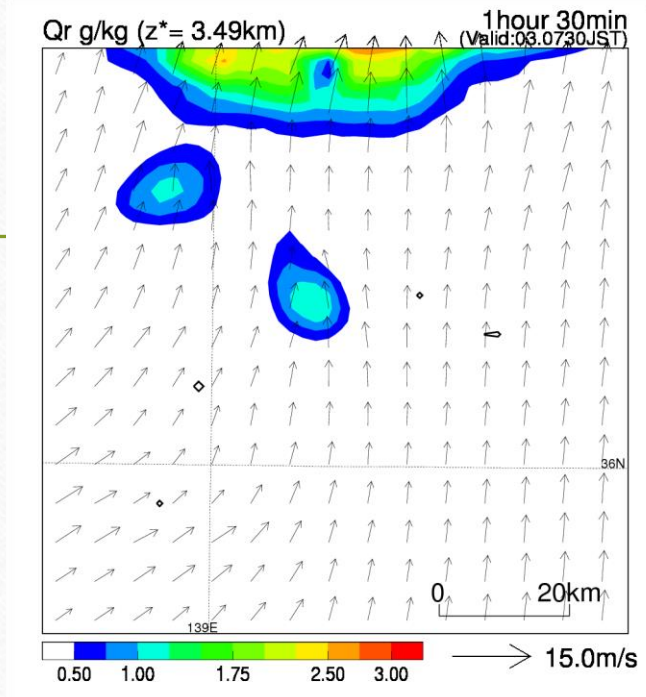
Nature run



PF



NoDA

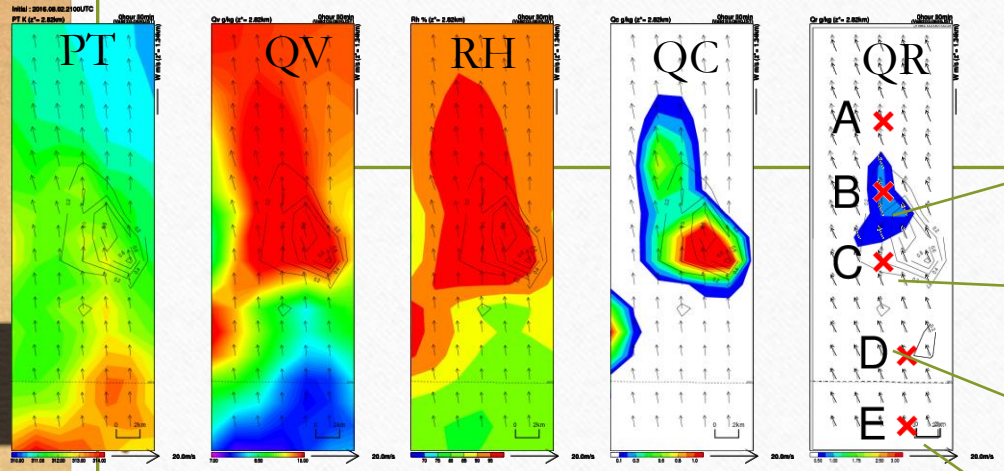


Convection Initiation!

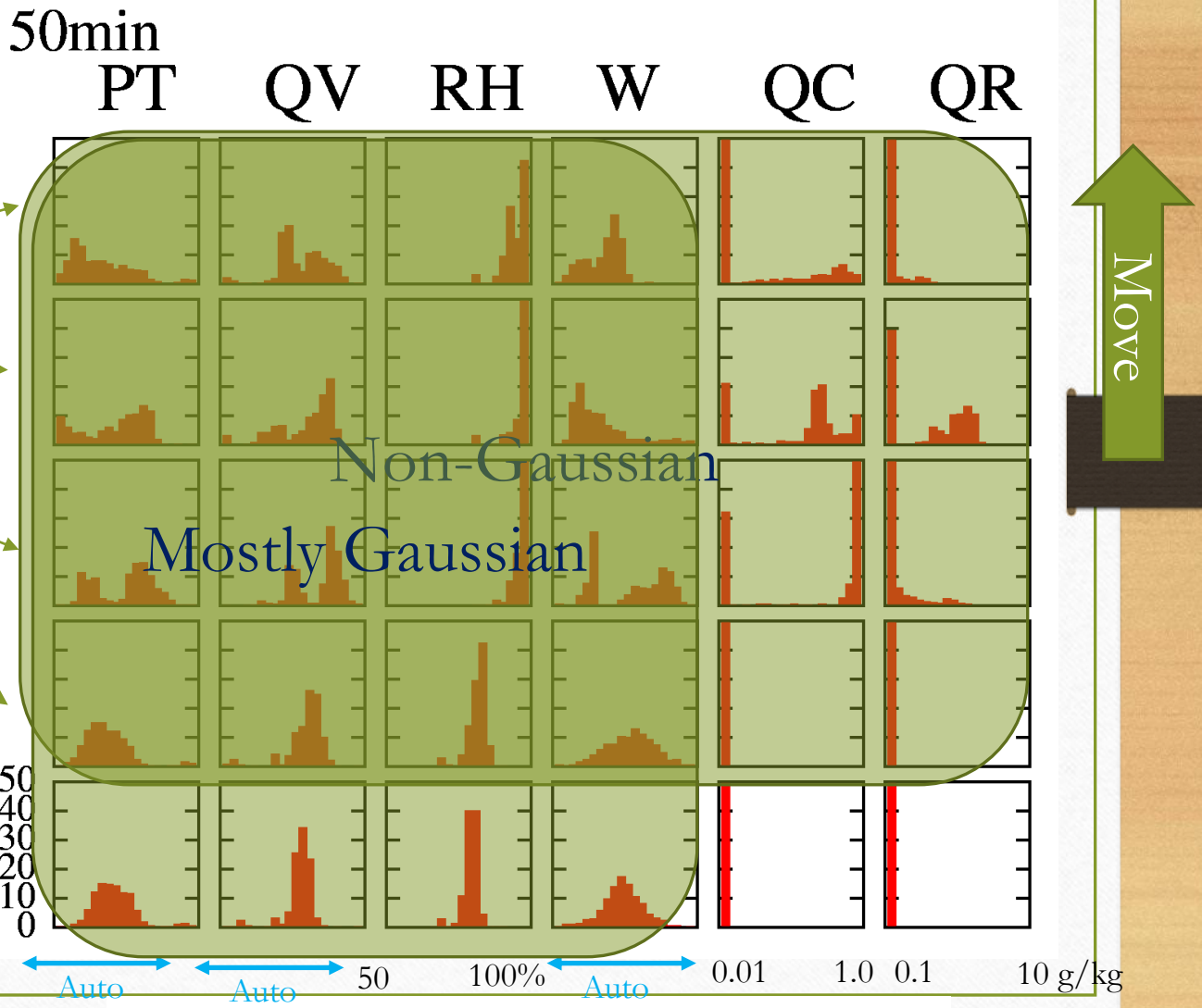
- The initiation timing of CI was improved.
- Intensity and horizontal scale of Cb core were significantly improved by NHM-RPF.

Predicting Non-Gaussian PDFs for Severe Local Storms

Ensemble mean



Contours: W

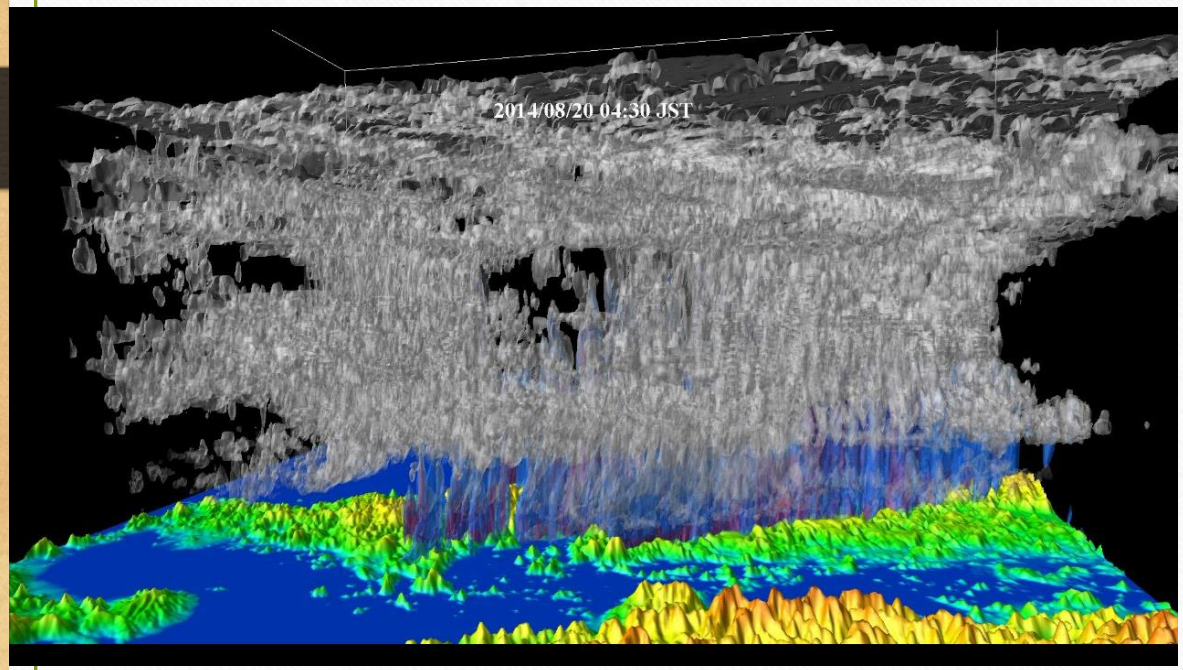


X-axis: Max-Min at each grid for PT, QV, W.
Fixed for RH,QC,QR.

Impact-based Forecast

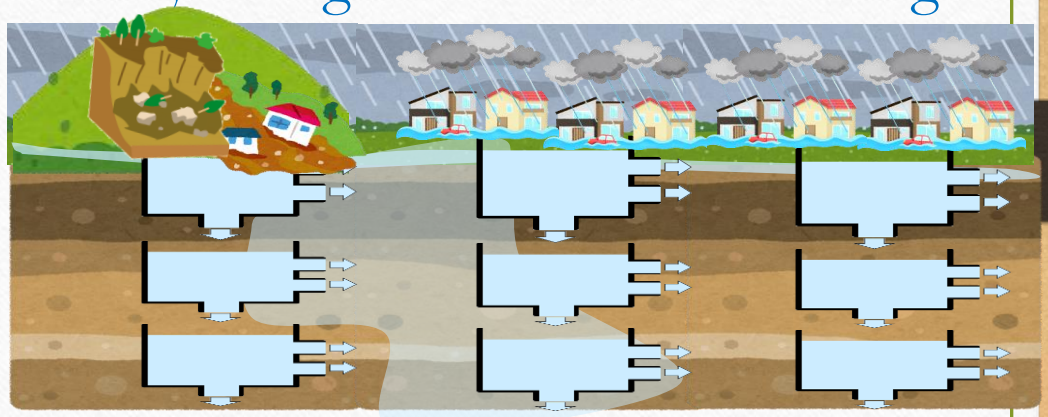
Predicting hazard (impact on people's life)
under collaboration of
meteorology, hydrology, oceanography, etc

Numerical Weather Prediction Model



Oizumi et al. 2020

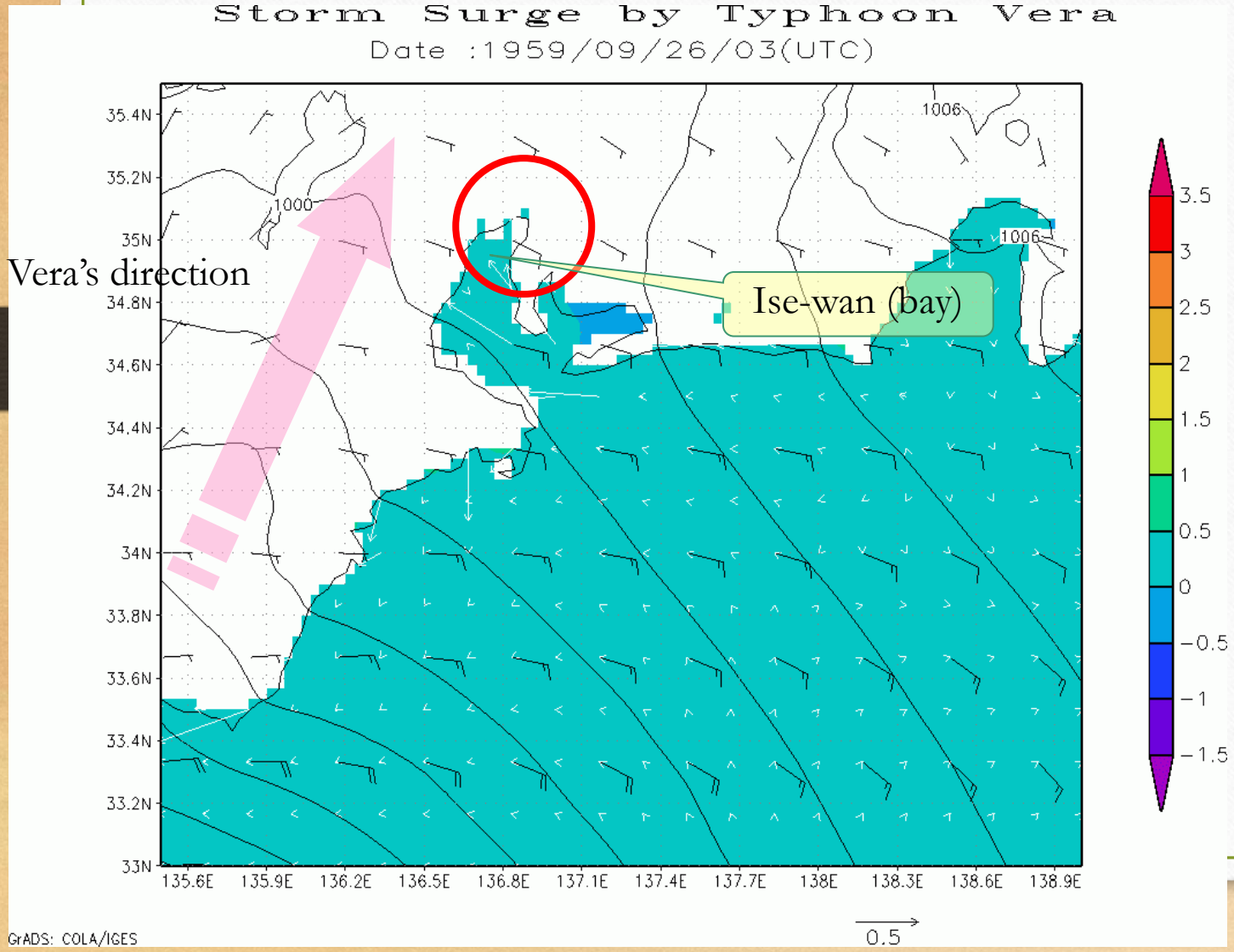
Hydrological Model for Flooding

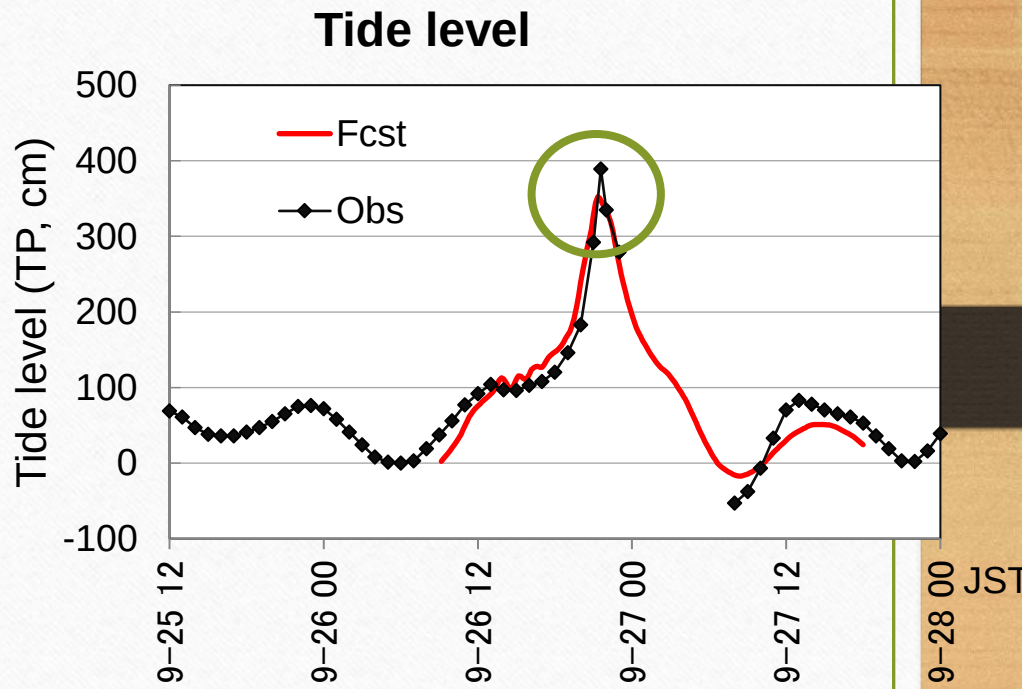


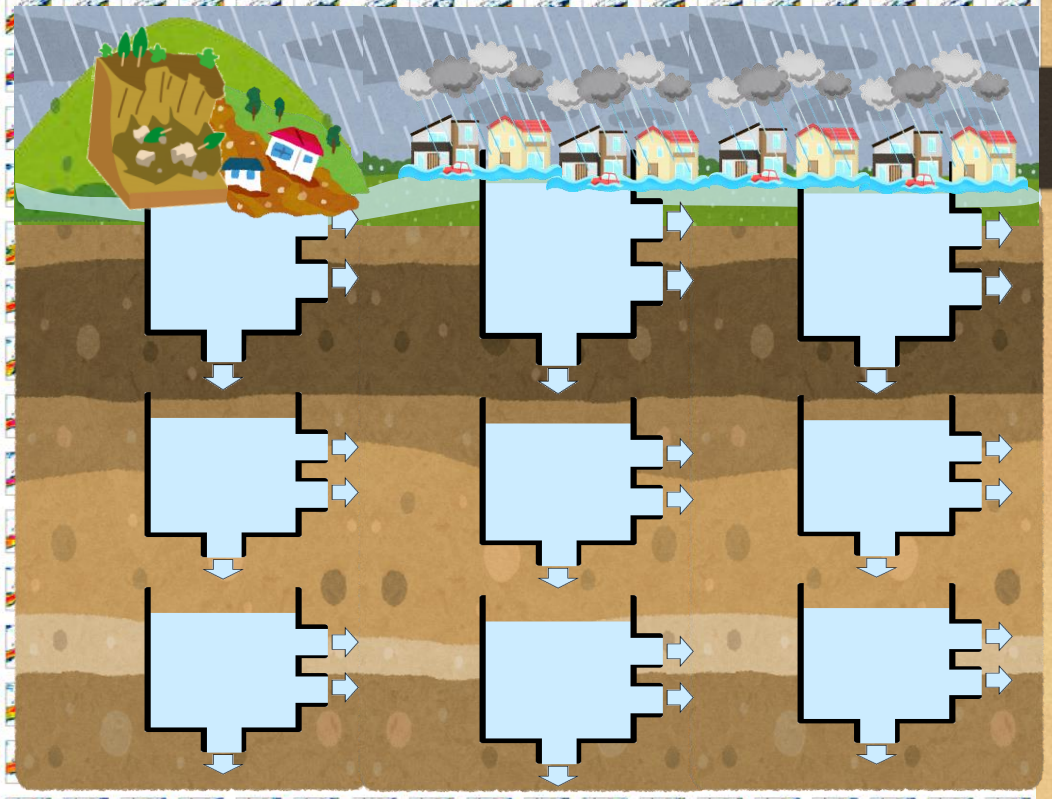
Oceanographic Model for storm surge

Impact-based

Predicting Storm Surge by Typhoon Vera (1959)



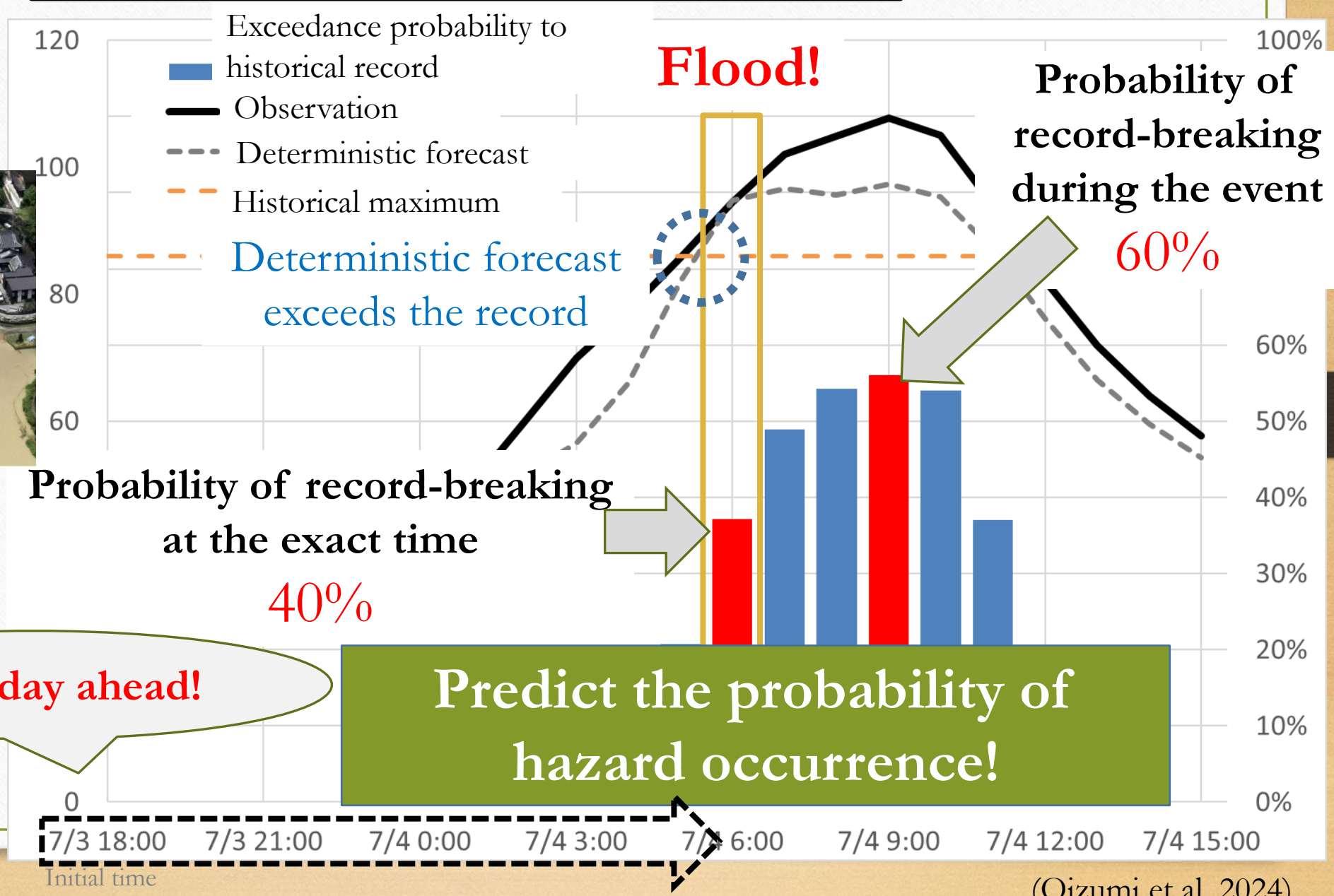




Impact-based

Run-off Index

Senju-en (Sankei)



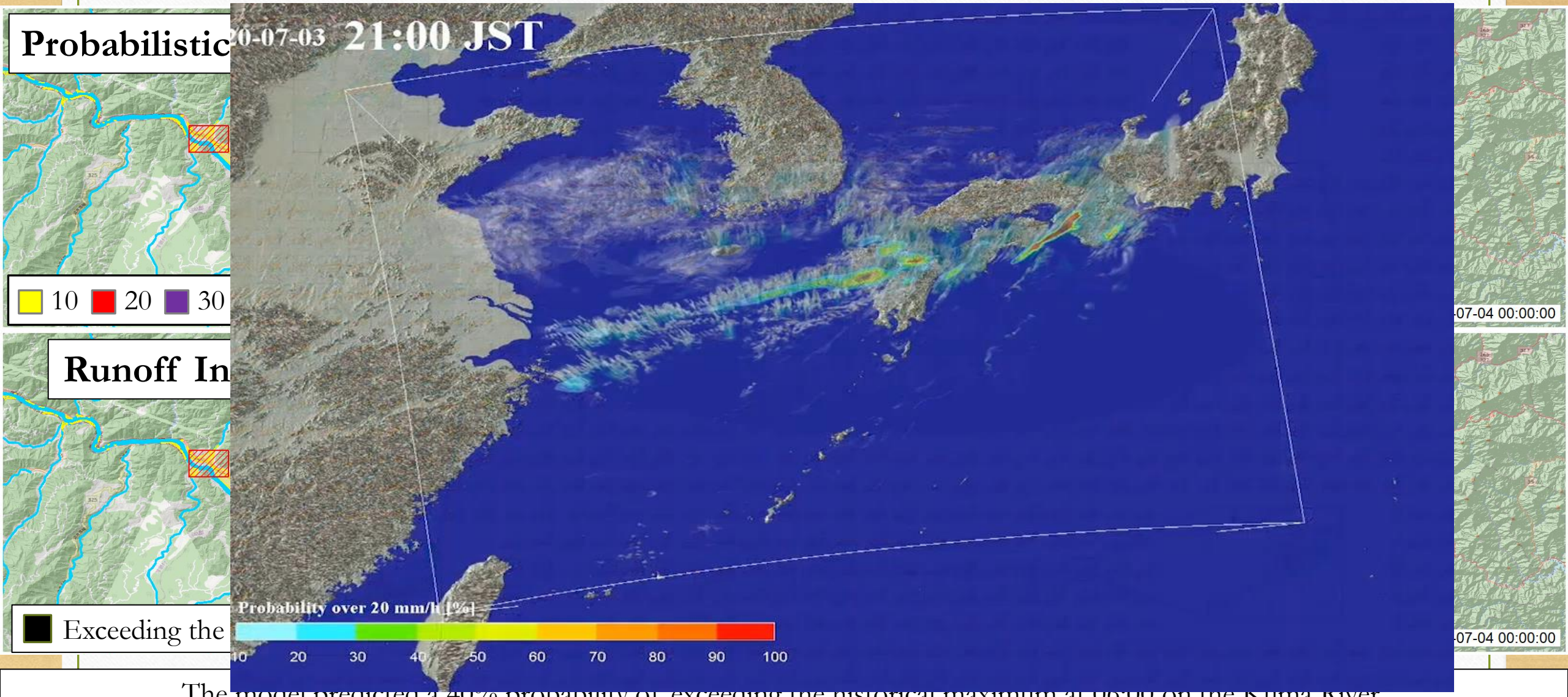
A half day ahead!

Predict the probability of hazard occurrence!

(Oizumi et al. 2024)

Impact-based

Probability of exceeding the historical maximum



The model predicted a 40% probability of exceeding the historical maximum at 06:00 on the Kuma River.

(Oizumi et al. 2024)

Toward Successful Forecast on Severe Local Storms

—Beyond Weather Forecast—

1. Data Assimilation
   High-frequent and dense remote-sensing observations
   Advance data assimilation (4D-Var, EnKF, EnVar, PF)
2. Probabilistic Prediction
   Large ensemble for less sampling errors
   Explicit non-Gaussian PDF
3. Impact-based Forecast
   Coupled with hydro-, storm-surge-models

Thank you for your attention

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in Journal of the Meteorological Society of Japan (**JMSJ**)
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(SOLA) In special editions of 2023-2024

Deadline of submission: August 31 2024

- Many simulation studies in meteorology, oceanography, atmospheric chemistry, and other related sciences have been conducted using high-performance computing (HPC) technology,.
- The advent of such HPC facilities has contributed to significant progress in atmospheric science by allowing for super-high resolution simulations, large ensemble simulations, and assimilation of observational big data.
- **This special edition accepts papers on meteorology, climate change, and environmental science with high-performance computing technology**

Death Tolls by Natural Disasters in Japan