Increasing Frequency of Anomalous Precipitation Events in Japan Detected by a Deep-Learning Autoencoder

Hiroyuki Murakami, T.L. Delworth, W. Cooke, S. Kapnick, P.-C. Hsu

NOAA-GFDL/UCAR

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1. Motivation

Increasing extreme precipitation in Japan (IUGG2023-513)

H. Murakami (GFDL/UCAR)

The frequency of extreme precipitation events has been increasing in Japan. Is this due to global warming?

The three key questions and challenges were addressed

Effect of Natural Variabilities and Global Warming

How to Objectively Define Extreme Precipitation Events?

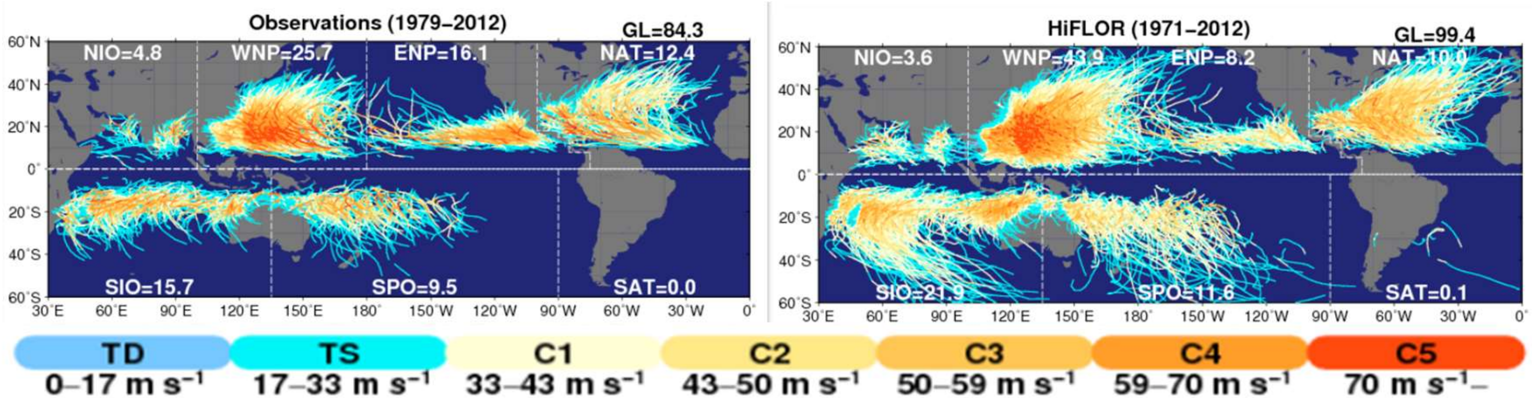
Resolution Issues in Climate Models

To tackle these, we applied and utilized:

- **Large-ensemble experiments,**
- **High-resolution model (HiFLRO & SPEAR),**
- **A deep learning method –Autoencoder –.**

2. Dynamical Models (HiFLOR and SPEAR)

- HiFLOR: Fully coupled model with 25km-mesh atmosphere and 1° ocean/sea ice



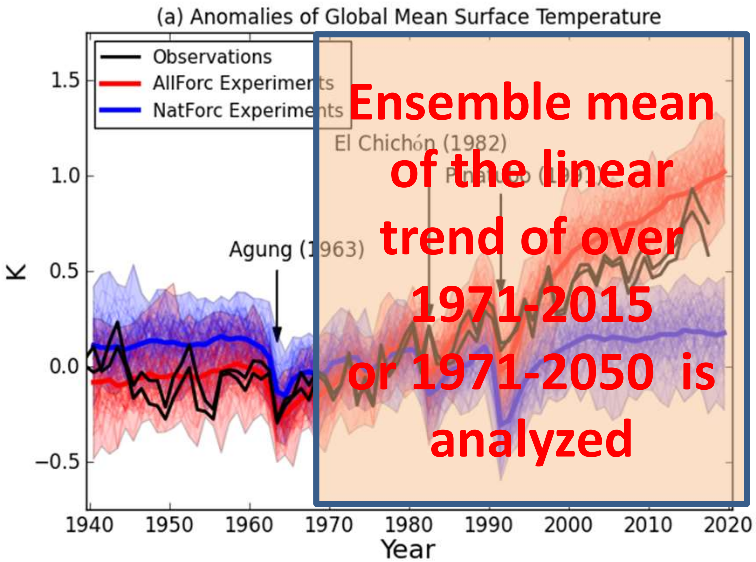
Observed (left) and simulated tropical cyclones by HiFLOR (right) over the period 1971-2012.

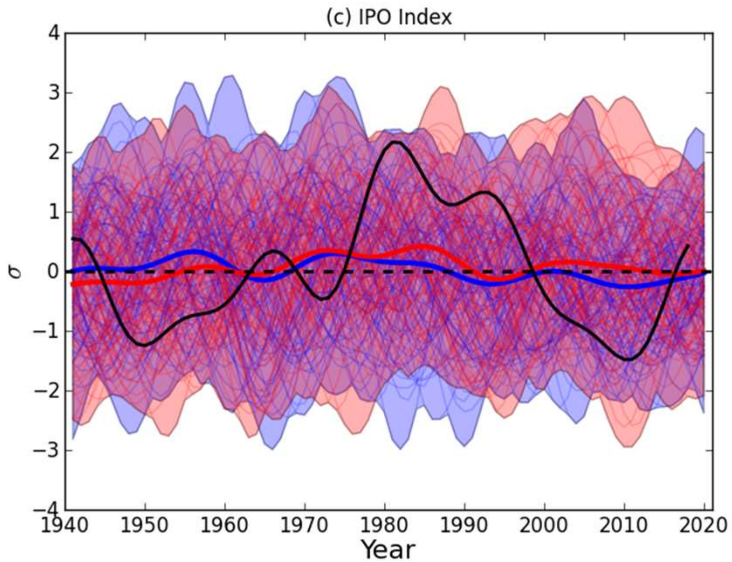
- SPEAR : Fully coupled model with 50km-mesh atmosphere and 1° ocean/sea ice
  - The next generation S2D prediction model at GFDL
  - Realistic predictions and simulations of tropical cyclones over the Western North Pacific (Delworth et al. 2020, *JAMES*)

3. Large-Ensemble Experiments

AllForc: 1941-2014: Historical simulations by prescribing time-varying external forcing (green-house gasses, aerosols, volcanic forcing, and solar constant)
2015-2050: RCP4.5 Scenario for HiFLOR and SSP5-8.5 Scenario for SPEAR
Ensemble members: SPEAR (30 members), HiFLOR (15 members)

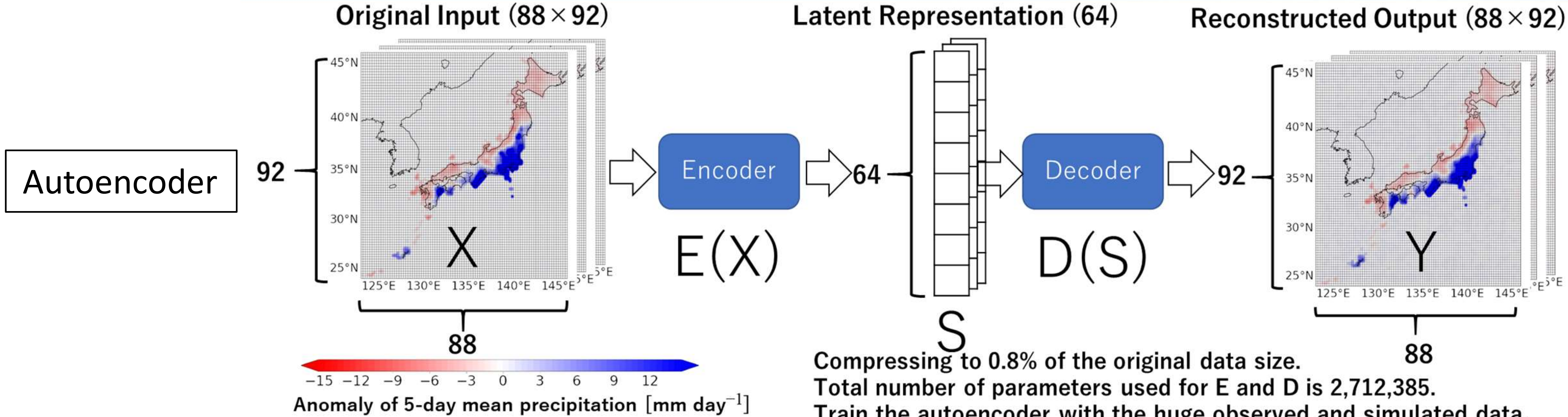
NatForc: As in AllForc, but only with time-varying volcanic forcing and solar constant.
Ensemble members: SPEAR (30 members)



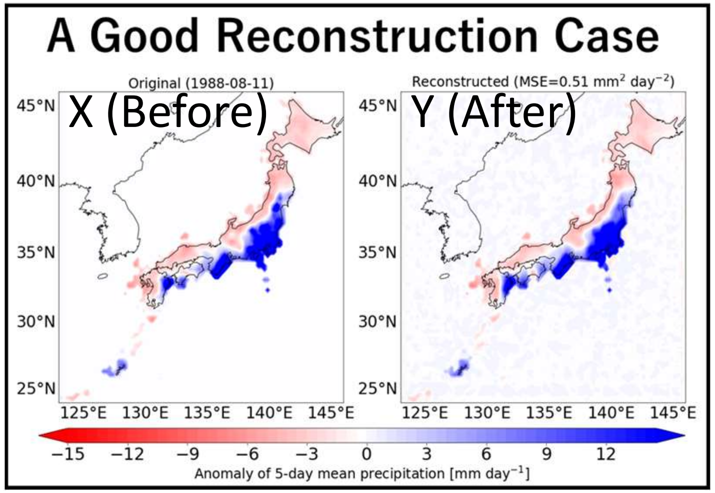


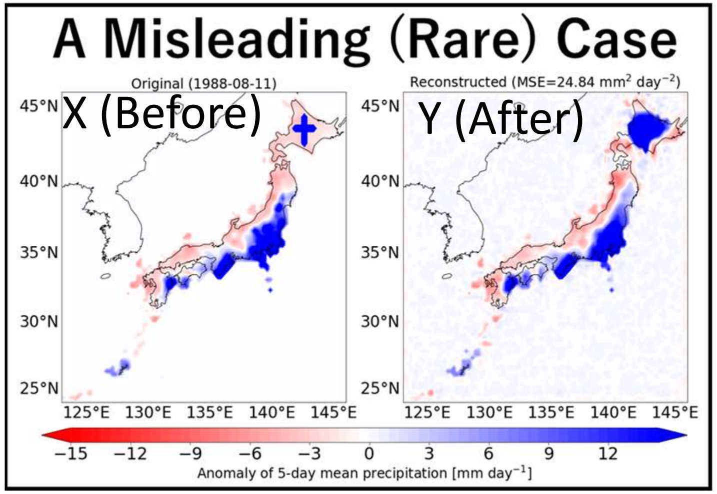
Each ensemble member shows different phase of internal variability. Internal variability can be canceled out by averaging the members.

4. Autoencoder –A Deep Learning Technique–



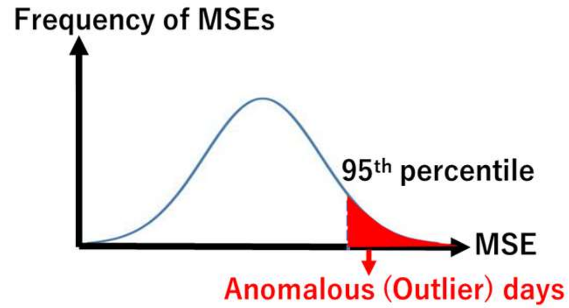
Compressing to 0.8% of the original data size.
Total number of parameters used for E and D is 2,712,385.
Train the autoencoder with the huge observed and simulated data.



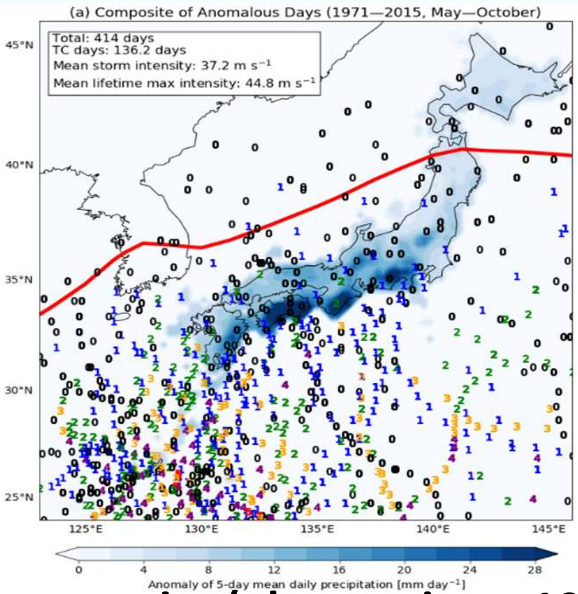


$$Autoencoder\colon Y = D(E(X))$$

$$MSE(t) = \sum_{j=1}^{92}\sum_{i=1}^{88}(Y_{i,j,t} - X_{i,j,t})^2$$



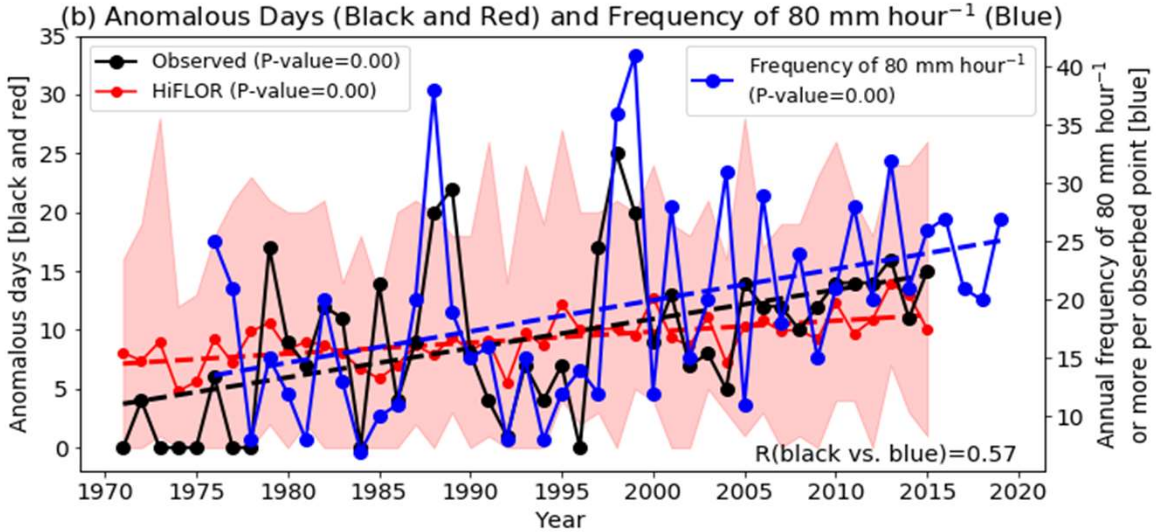
5. Outliers Detected by the Autoencoder



Outlier composite (observations, 1971-2015)

Shading : Anomaly of daily accumulated precip
Number : Locations of Typhoon with Saffir-Simpson category
Red Line : θ_e=325K（Mean location of Fronts)

A typical anomalous event is mostly associated with heavy precipitation accompanied by a frontal structure and intense typhoons.

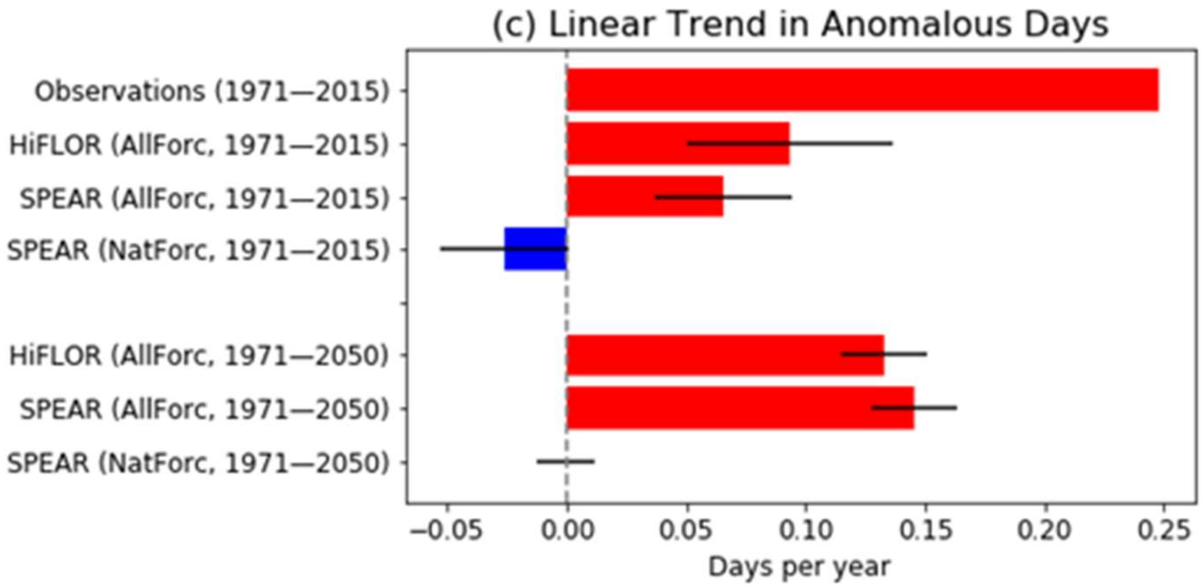


Interannual variation in outlier days（1971－2015）

Black : Outlier days by observations
Red : Simulated outlier Days by HiFLOR
Dashed: Statistical significant linear trend (95%)
Blue : Annual number of events with precipitation ≥ 80 mm h^{-1} per 1300 rain gauges

The simulated positive trend indicates that the observed positive trend over recent decades is attributable to increasing anthropogenic global warming.

6. Linear Trends in Outlier Days

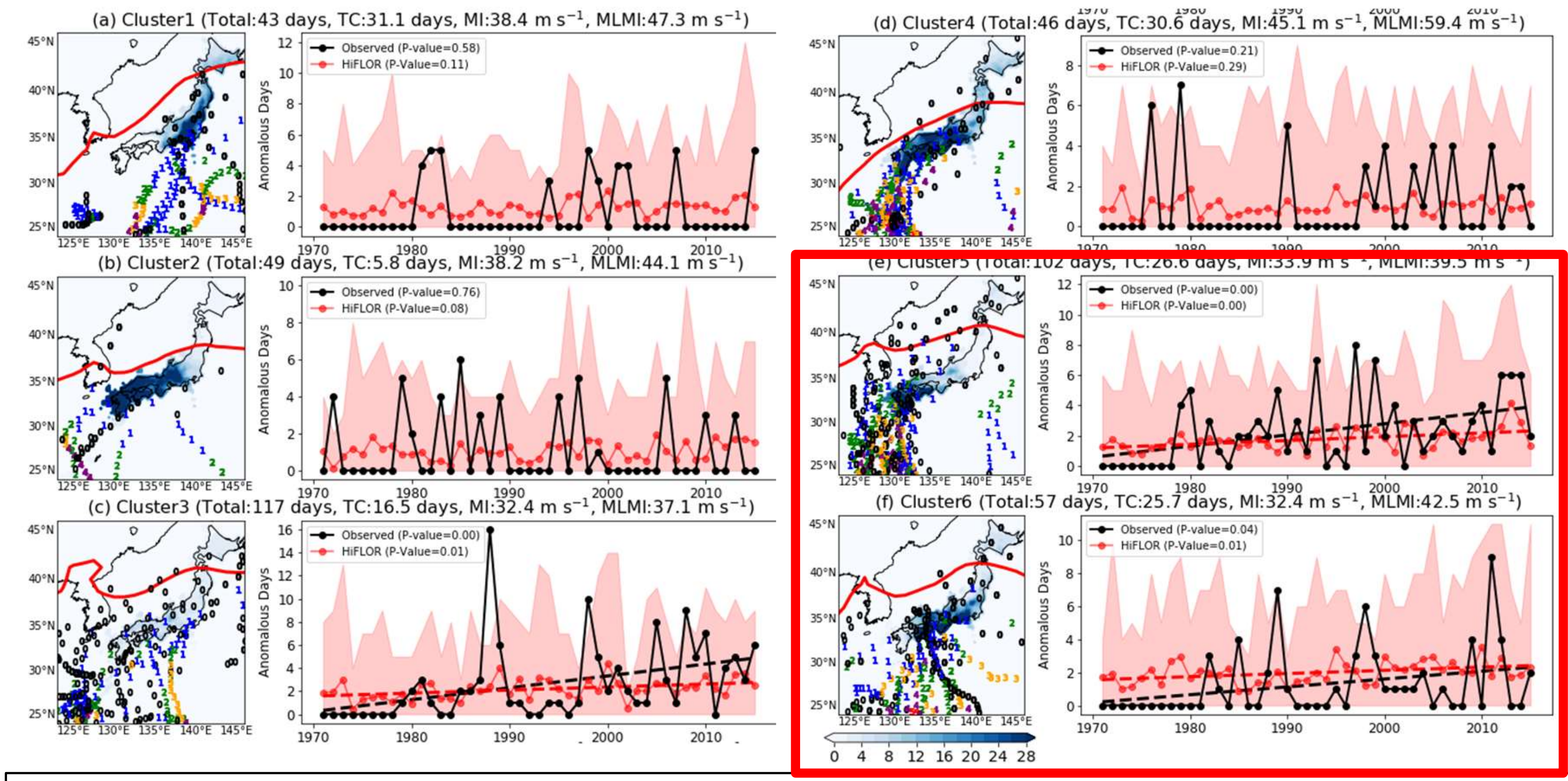


Linear trends in outlier days

Error bars in idcate ensemble spreads.

- Both observations and models show significant trends in outlier days (extreme events) over the last 50 years caused by global warming.
- The models project continuing increases in outlier days up to 2050.

7. Clustering of Outlier Days



The 6 clusters for outlier days by the *K*-mean cluster analysis

- Both observations and HiFLOR show significant increasing trends in Cluster5（Kyushu & Okinawa) Cluster6 (Central Japan) related to intense typhoons.
- Increasing trends in Cluster 5 and 6 are related to increasing trends in typhoons approaching west Japan (see next slide).

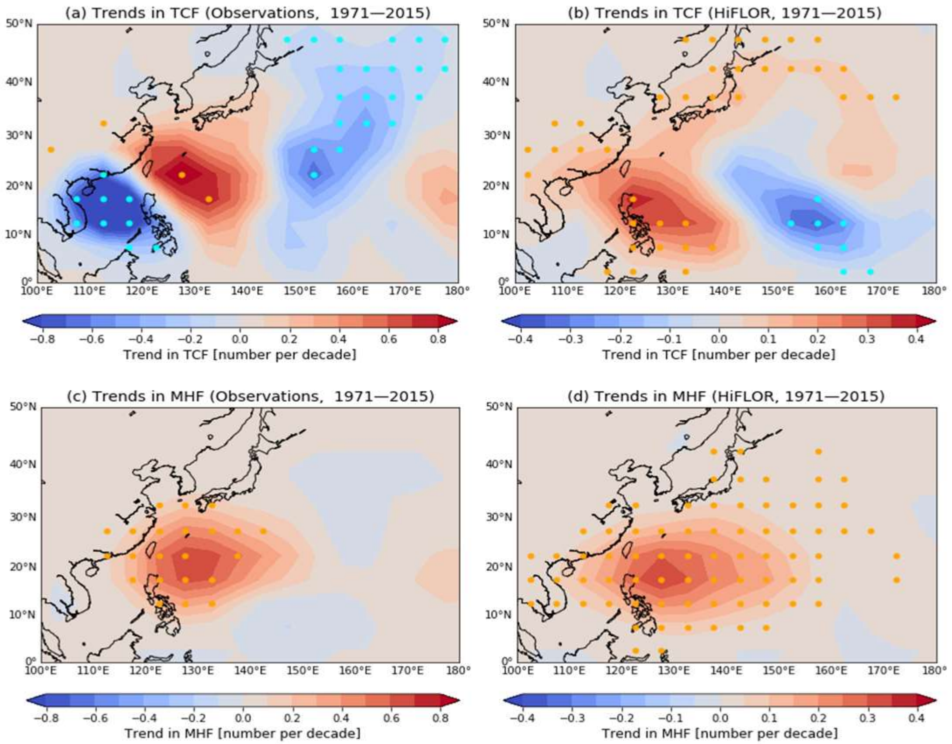
8. Trends in Tropical Cyclone Density

Observations （1971－2015）

HiFLOR（15-mem mean 1971－2015）

Trends in all storms （>17m/s）

Trends in intense Storms （>50m/s）



- Both observations and HiFLOR show increasing trends in frequency of occurrence in the southwest Japan.
- Note that the trends by HiFLOR are from the ensemble mean. Because the effect of natural variability is canceled out in the mean, the computed trends are due to increasing anthropogenic forcing.
- HiFLOR also projects increasing trends in intense storms near Japan in the future (figure not shown).

9. Summary

- Global warming is largely related to the observed increasing trends in extreme precipitation events in Japan over the last 50 years.
- The increases are specifically significant in Kyushu & Okinawa and Central Japan. And the increases are related to the increasing trends in frequency of intense typhoons approaching to the regions.
- The increases in intense typhoons near Japan are also due to the effect of global warming.
- It is expected that frequency of extreme precipitation and typhoon approaches to Japan would increase up to 2050.
- A deep learning is useful for climate science, but it is a work in progress.