Advancements in Diverse Event Attribution Techniques and Their Engagement with Society

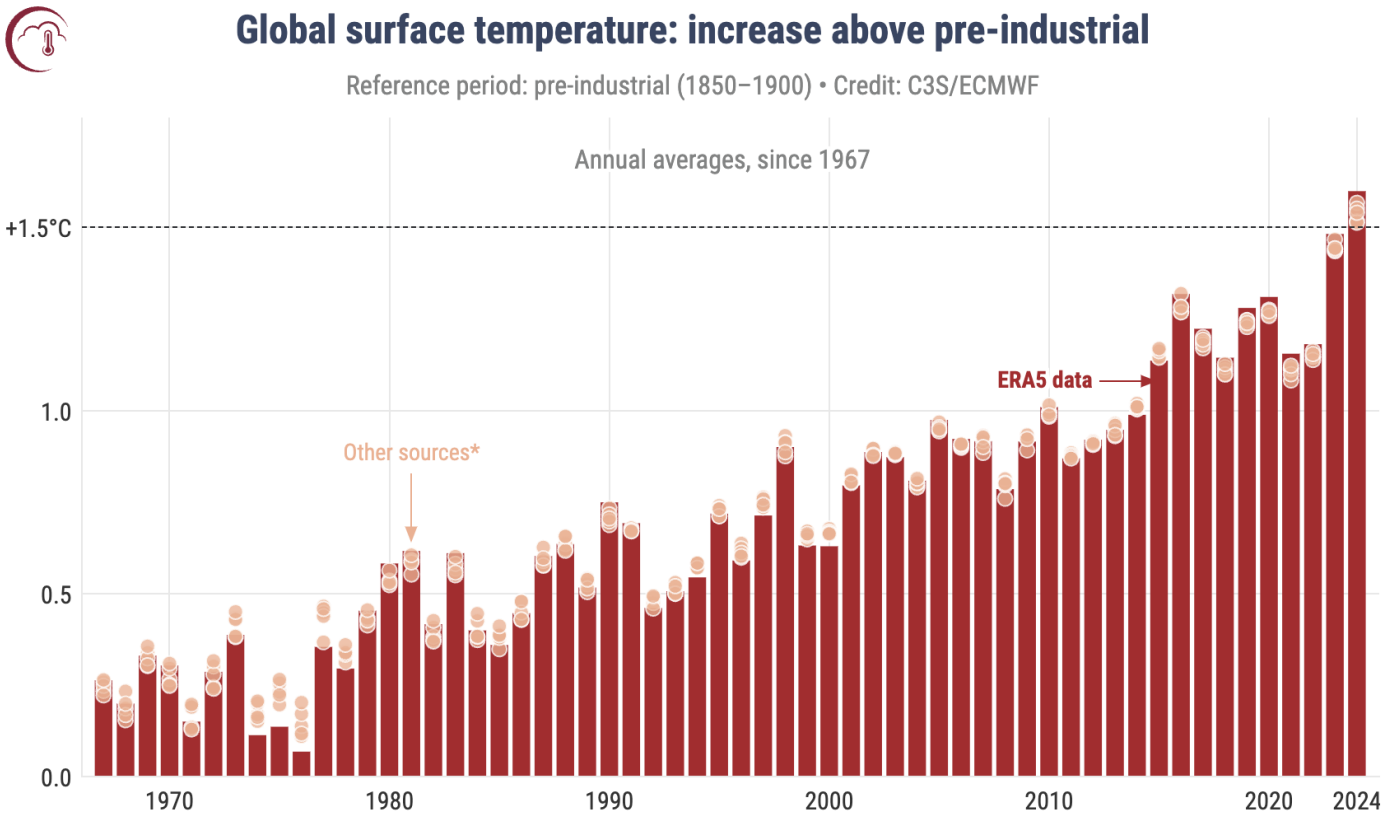
Yukiko Imada (Associate Professor, AORI, the Univ. of Tokyo)
On behalf of the Japanese EA team

d4PDF SINCE 2015

Weather Attribution Center Japan

AORI UTokyo

+1.5°C: Just Around the Corner



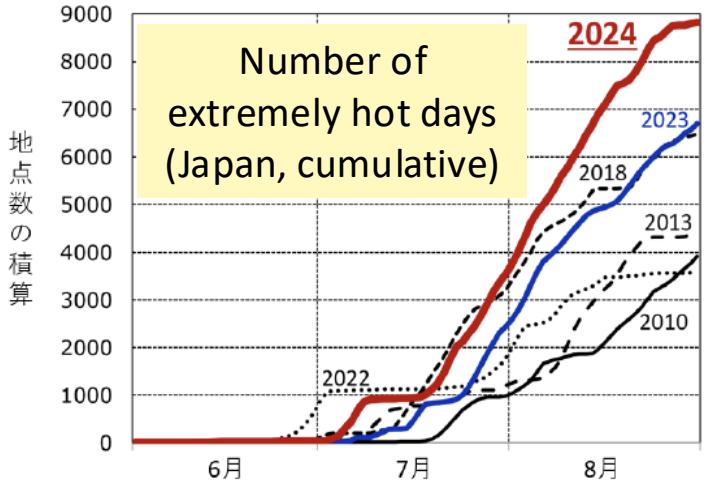
Copernicus Global Climate Report 2024 confirms last year as the warmest on record, first ever above 1.5°C annual average temperature.

The global average temperature in 2024 broke previous heat records, exceeding +1.5° C above pre-industrial levels for the first time as an annual average.

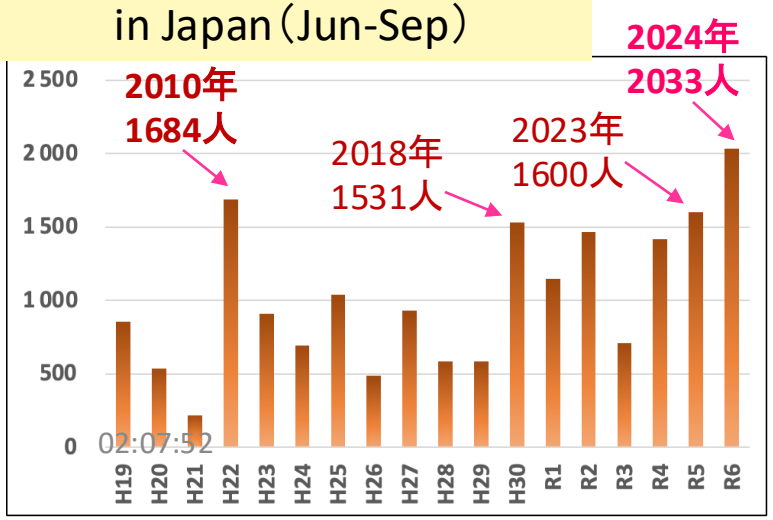
Copernicus Website
https://climate.copernicus.eu/global-climate-highlights-2024

Extreme heat in Japan, 2024

Number of extremely hot days (Japan, cumulative)

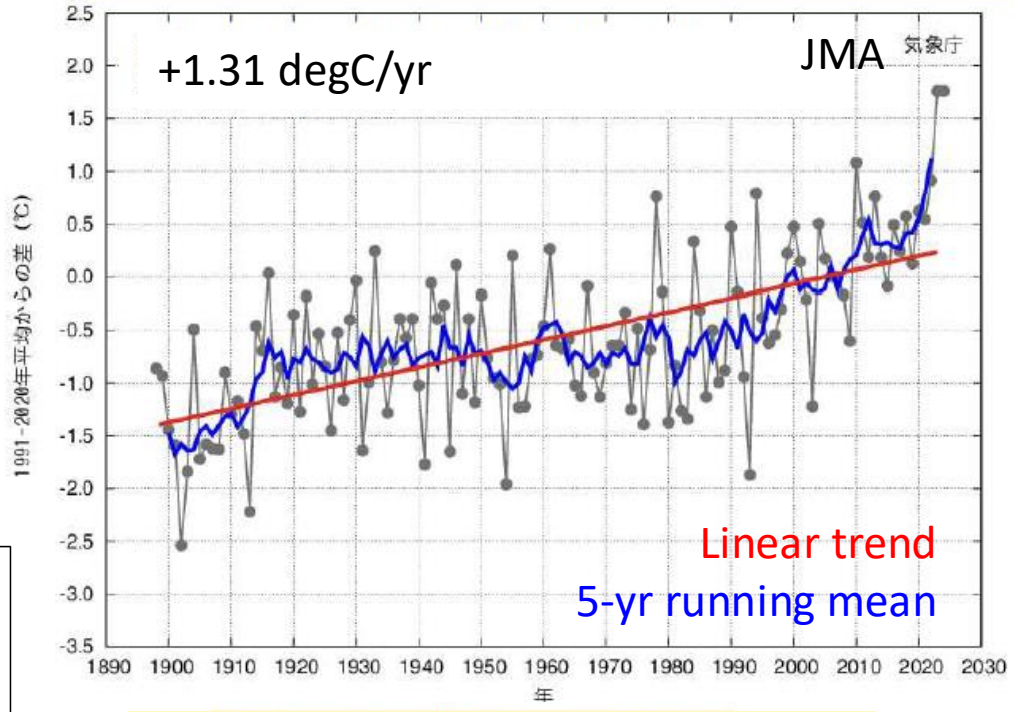


Heatstroke-Related Deaths in Japan（Jun-Sep）

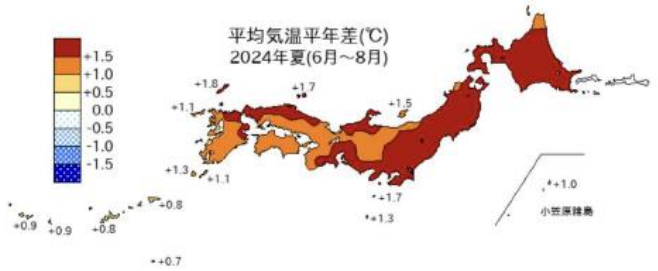


Ministry of Health, Labour and Welfare, Japan

Summer temperature anomaly in Japan



Summer 2024 temperature anomaly



Sea surface temperature

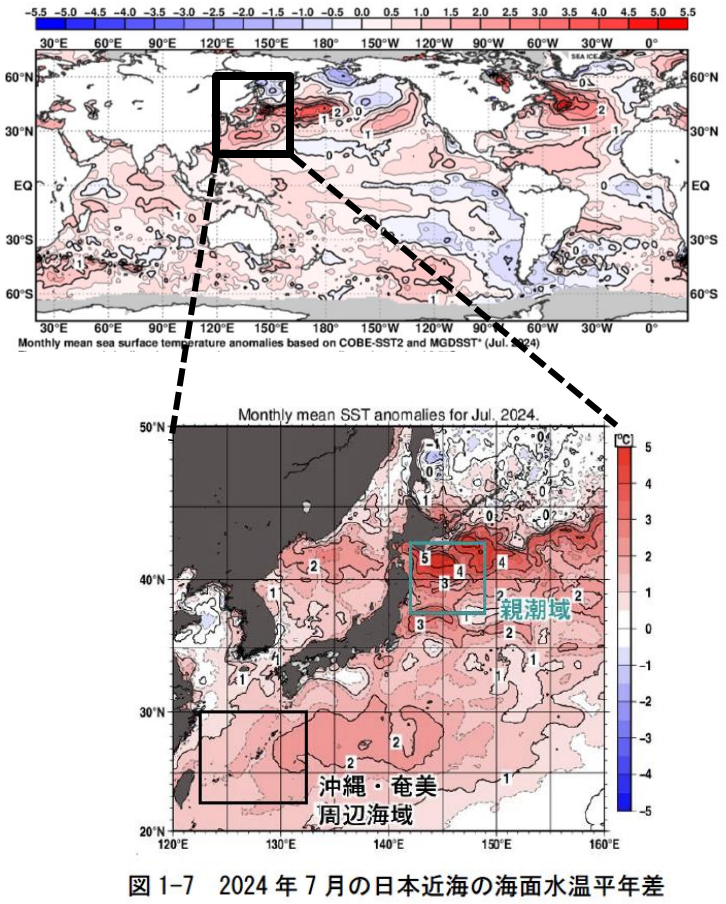


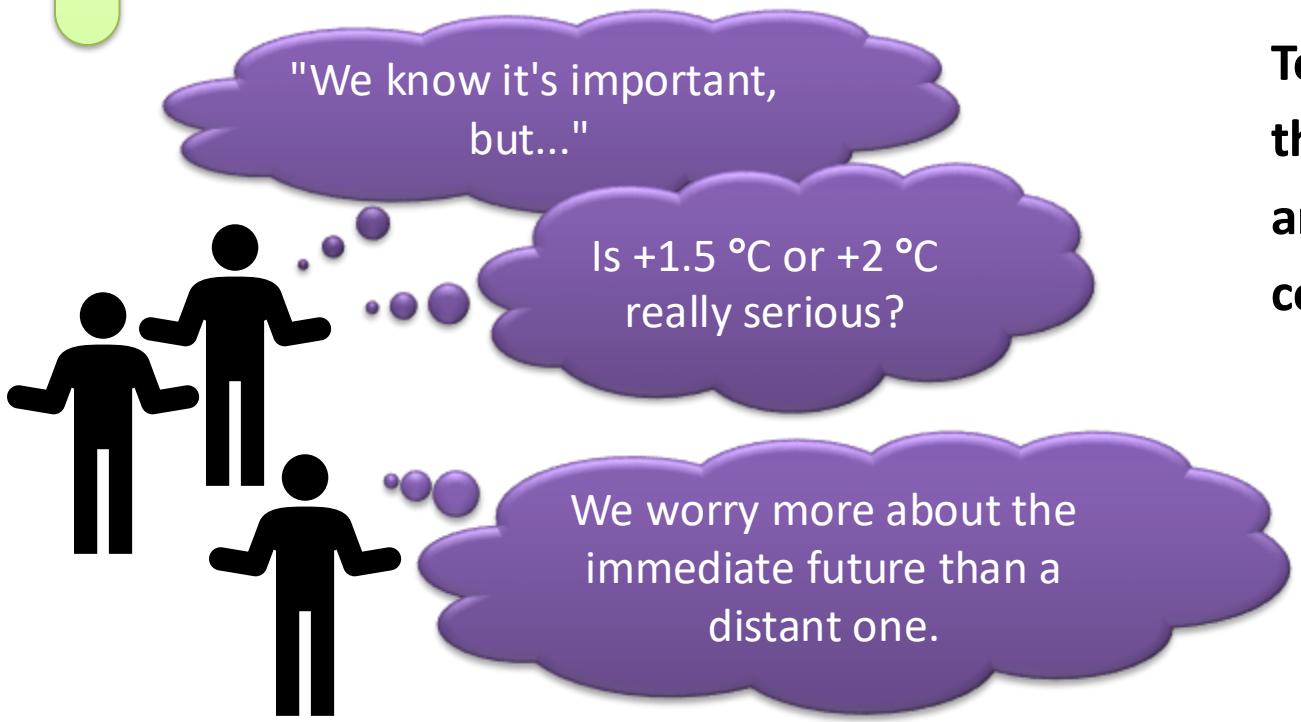
図 1-7　2024 年 7 月の日本近海の海面水温平年差

JMA (2024/09/02)

Voices from the public: “Is +1.5 °C or +2 °C really serious?”

IPCC AR6 SPM

- “Global warming of 1.5℃ and 2℃ will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades.”
- “Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, … heavy precipitation, … droughts, … intense tropical cyclones, …”



To achieve a decarbonized society, it is essential that the national and local government, private sector, and the public share a sense of urgency and contribute to shaping public opinion.

Tools that stimulate a sense of reality and imagination

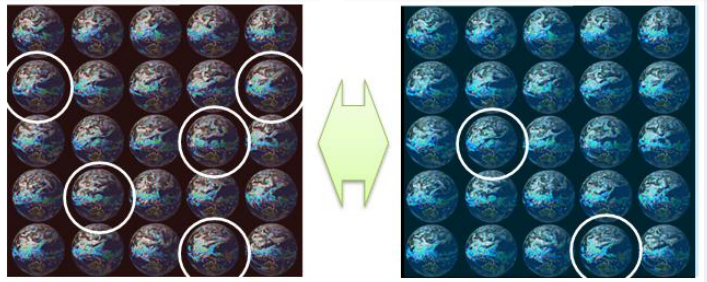
Event Attribution

Two conventional approaches of EA

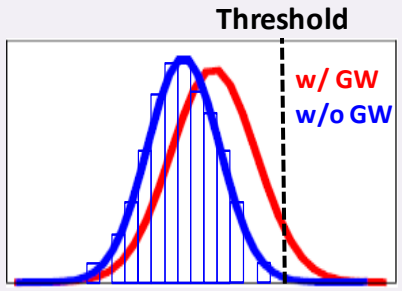
Will the probability (frequency) of extreme event increase with global warming?

Realistic climate simulation (w/ GW)

Counterfactual climate simulation (w/o GW)

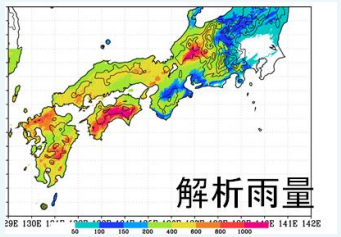


Compare probability density distributions

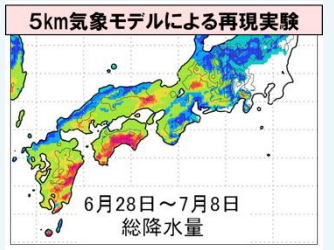


- To understand what other random weather events could have occurred, generate a large ensemble of climate simulations under conditions with and without warming,
- Count the proportion of ensemble members under the two conditions that reproduce extreme events similar to the observations, and compare their occurrence probabilities.

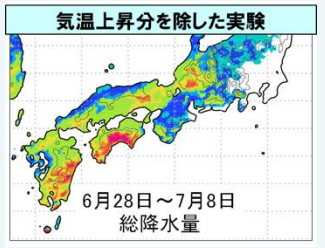
Will the intensity (severity) of extreme event increase with global warming?



Observed precipitation

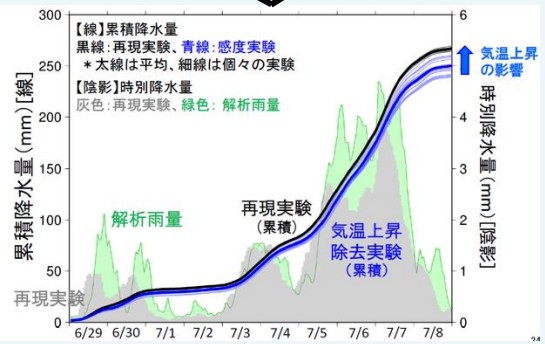


Reproduced by the model in forecast mode.



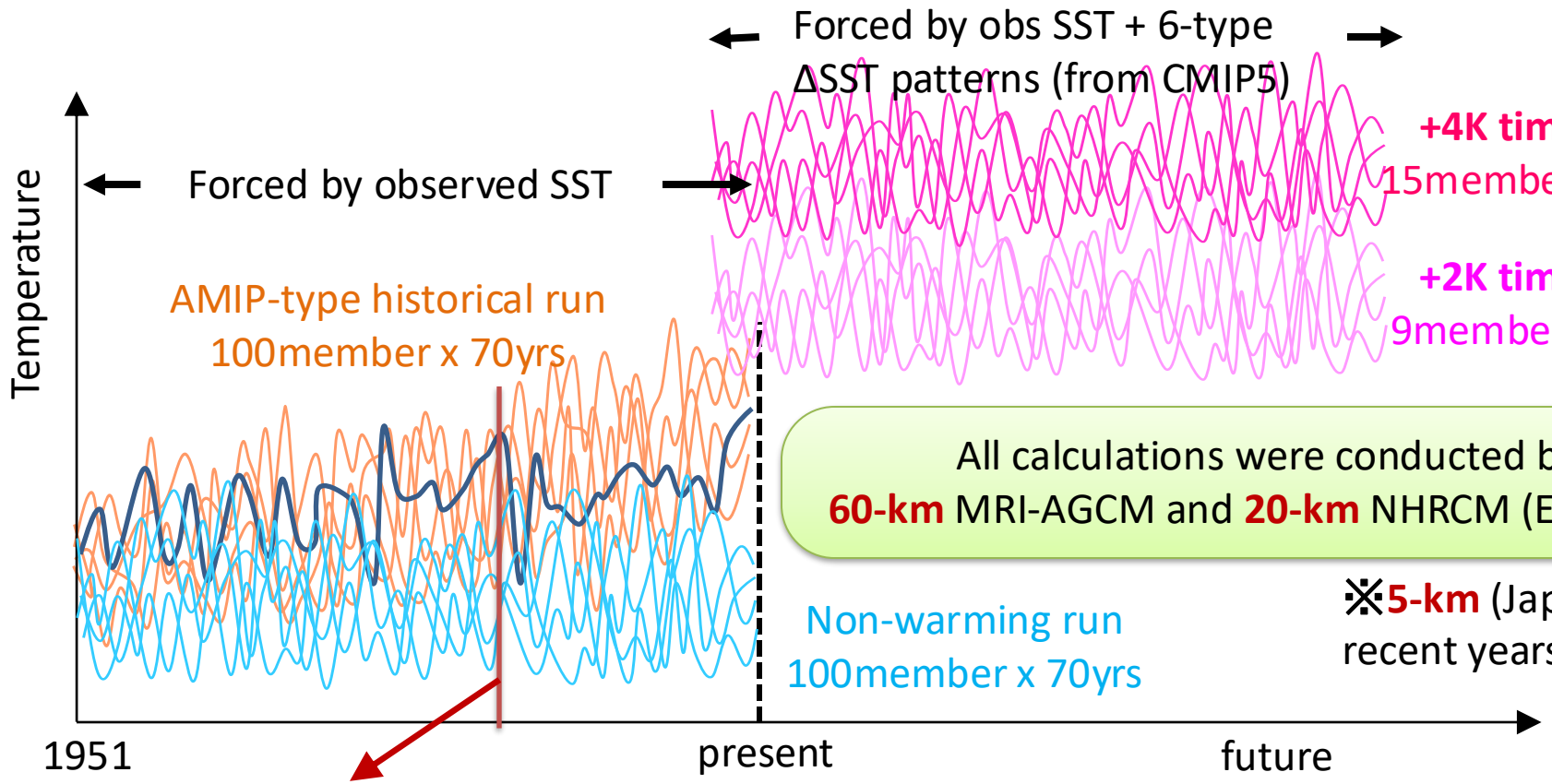
Remove the warming increment from the boundary conditions

- The event is assumed to occur under realistic initial/boundary conditions.
- Compare the intensity under two climate conditions



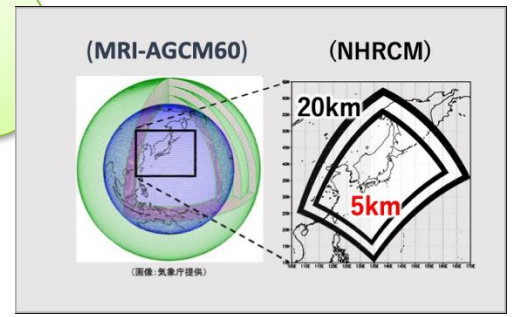
Compare the evolution of rainfall

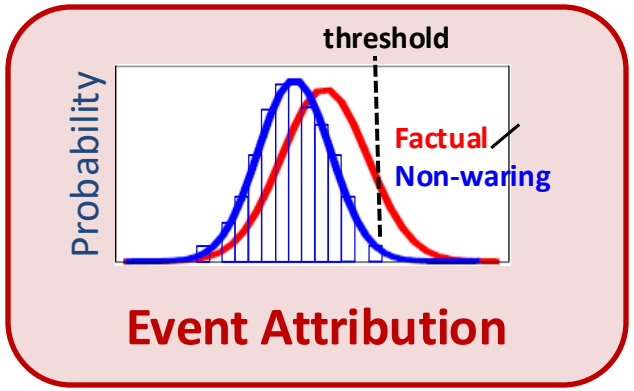
Basic strategy of risk-based Event Attribution in Japan



All calculations were conducted by **60-km** MRI-AGCM and **20-km** NHRCM (East Asia)

※**5-km** (Japan) for recent years



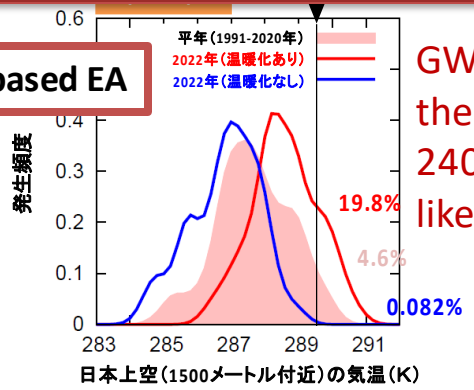


- High performance for East Asian climate due to dynamical downscaling
- The database is updated annually.
- Conduct irregular emergency calculation when an extreme event occurs (1-2 months for calculation and analysis)
- Prescribed by the observed SST and Sea Ice. -> Calculation cannot be started before we obtain the observed variables.

Links between recent extreme weather in Japan and global warming

Extreme heat in late June to early July 2022

Risk-based EA

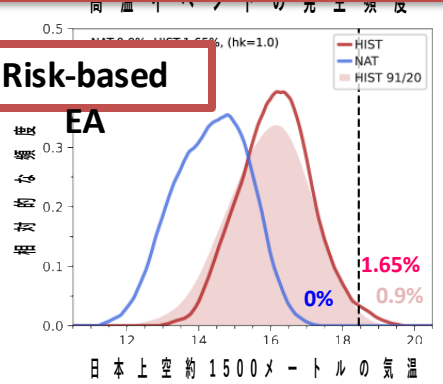


GW has made the event about 240 times more likely.

2022.9.6 press release (MEXT, JMA)

Extreme heat in late July to early August 2023

Risk-based EA

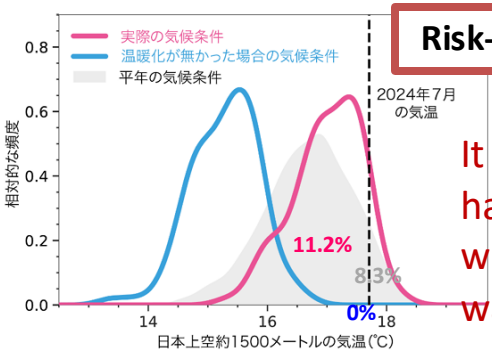


It would not have occurred without global warming.

2023.9.19 press release (MEXT, JMA)

Extreme heat in July 2024

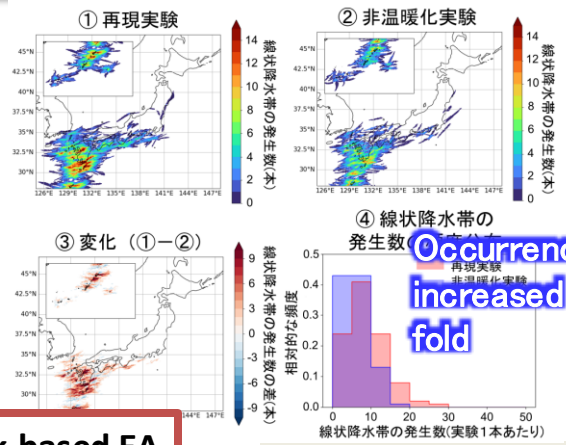
Risk-based EA



It would not have occurred without global warming.

2024.9.2 press release (MEXT, JMA)

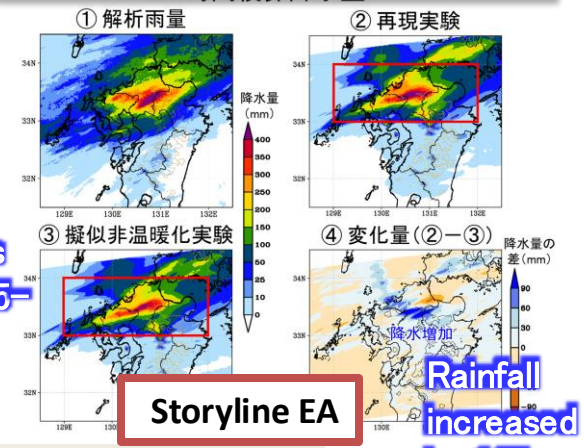
June-July 2023 rain band



Occurrences increased 1.5–fold

Risk-based EA

9-10 July 2023 heavy rain

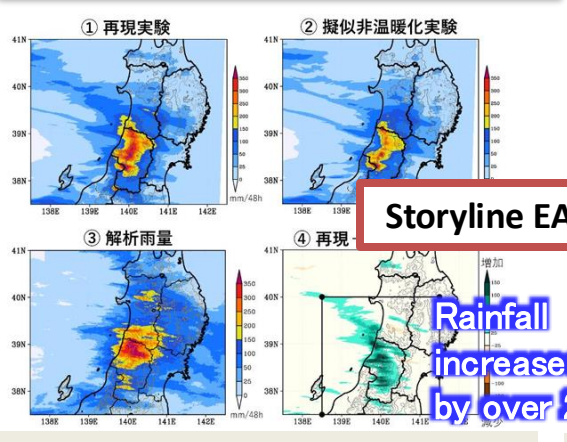


Storyline EA

Rainfall increased by 16%

2023.9.19 press release (MEXT, JMA)

24-26 July 2024 heavy rain

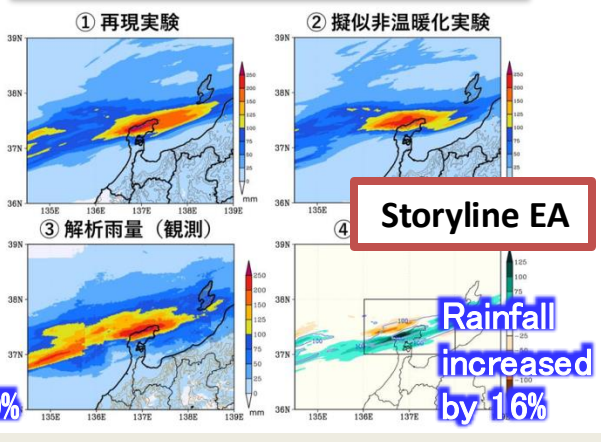


Storyline EA

Rainfall increased by over 20%

2024.9.2 press release (MEXT)

Sep 2024 heavy rain



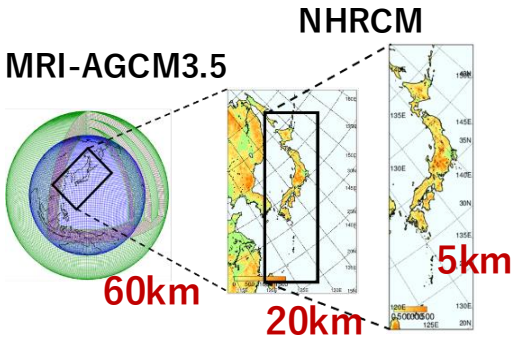
Storyline EA

Rainfall increased by 16%

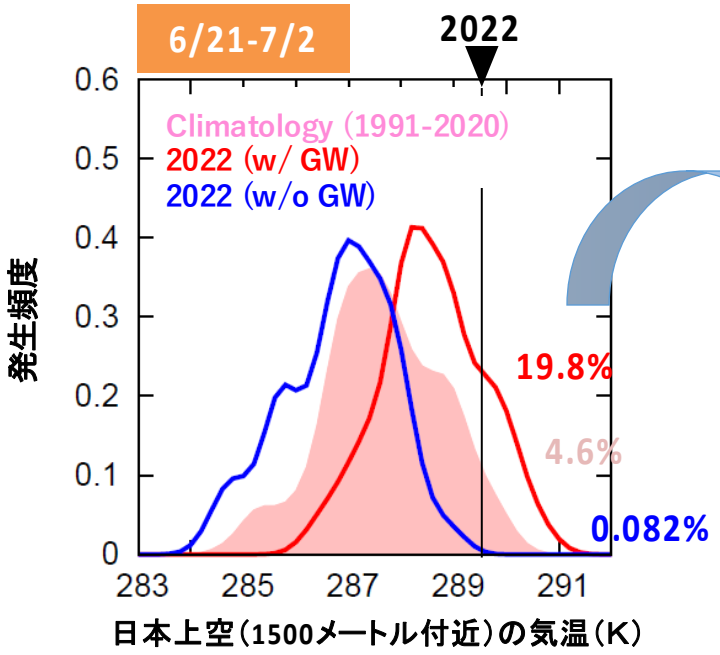
2024.12.9 press release (MEXT, JMA)

Operational EA in Japan: Predictive EA

Downscaled outputs



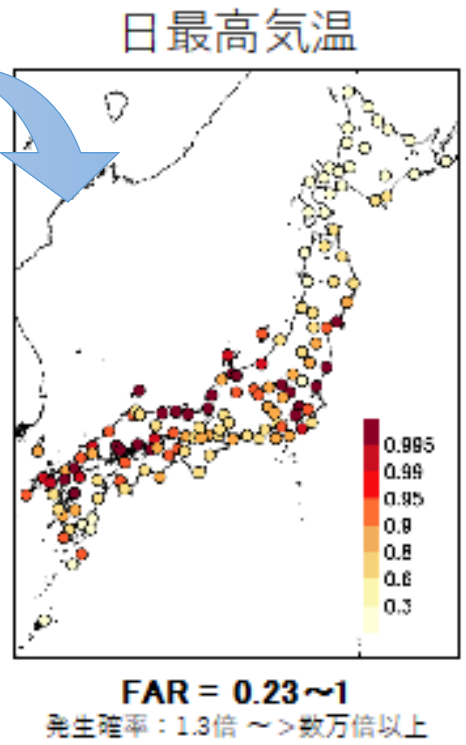
Heatwaves 2022 (6/21-7/2)

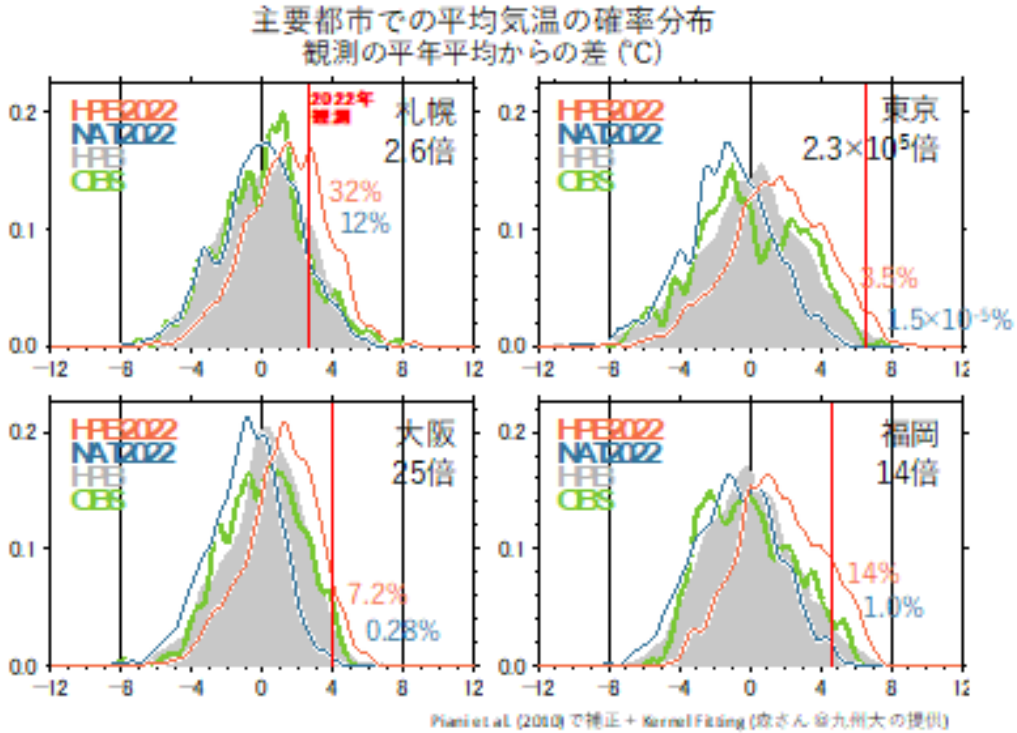


Risk Ratio ≒ 240

R. Ito et al. (2023)

Results of dynamical downscaling



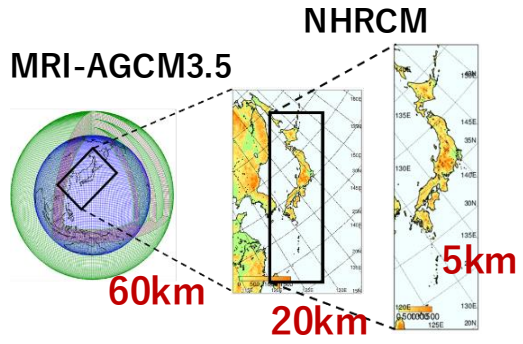


Providing city-by-city information

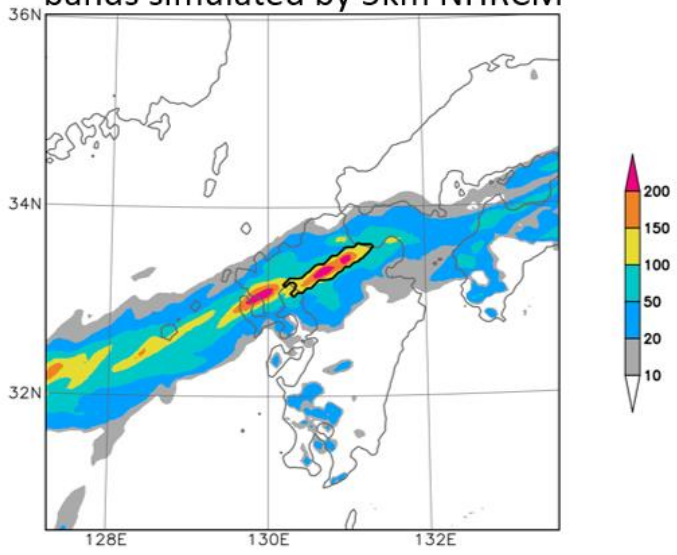
Operational EA in Japan: Predictive EA

Downscaled outputs

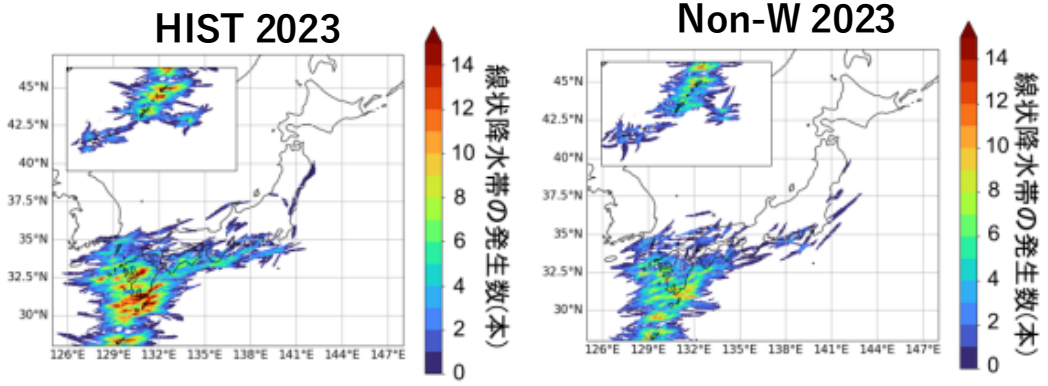
Heavy rainfall in 2023 (7/1-31)

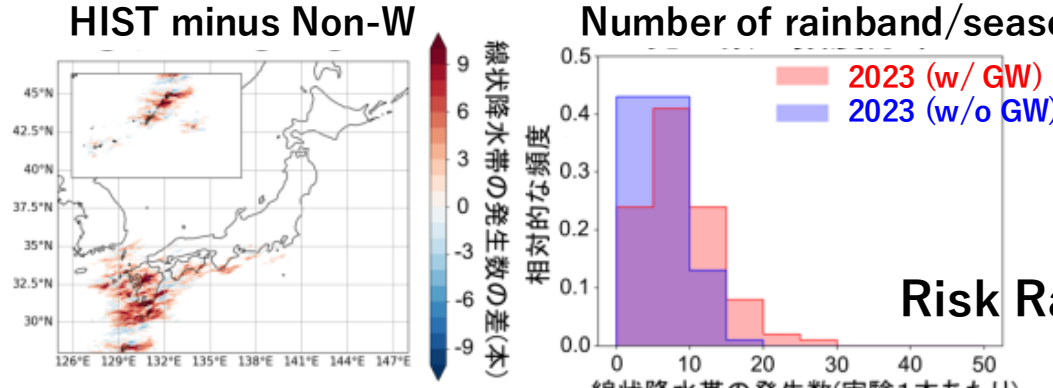


(a) A sample of quasi-stationary convective bands simulated by 5km NHRCM



Results of dynamical downscaling





Risk Ratio ≒ 1.5

S. Watanabe et al. (2024)

Actionable EA ～EA that leads to public action

◆ **Targeting variables relevant to everyday life in society:**

Focus on applied variables (flooded area, crop yields, health impacts) and socio-economic indicators (damage costs from disasters and insurance payouts)

Interdisciplinary approach

- Hydrology
- Agliculture
- Epidemiology
- Social science
- Economy

<u>Example of application to policy</u>

- **Flood Control Measures by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT)** "Water-related Disaster Management in the Context of Climate Change"
- **Flood Control Measures by Tokyo Metropolitan Government :** "The Role of River Infrastructure in the Context of Climate Change"
- **Other local governments are also considering phased implementation.**

Cases of interdisciplinary studies with hydrology

Flooded area due to Typhoon Hagibis

MOE 2020

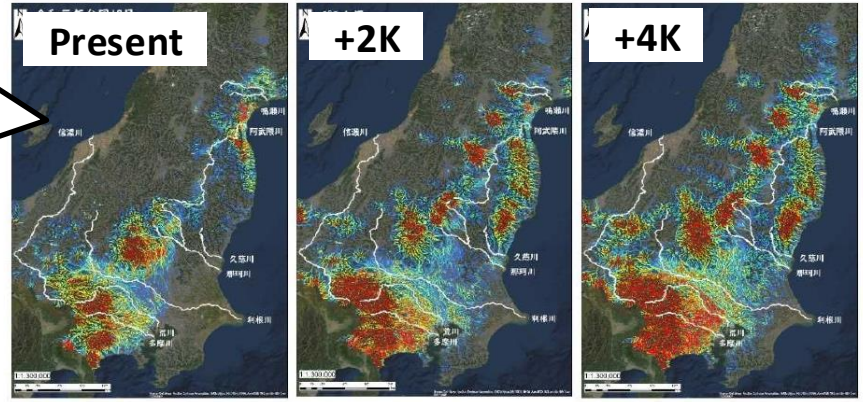


図13 ピーク流出高の変化（RRI、2℃上昇、4℃上昇シナリオは5ケースの平均を示す）

Actionable EA ～EA that leads to public action

◆ **Targeting variables relevant to everyday life in society:**

Focus on applied variables (flooded area, crop yields, health impacts) and socio-economic indicators (damage costs from disasters and insurance payouts)

Hydrology
Agliculture
Epidemiology
Social science
Economy

◆ **Rapid information dissemination:**

EA that requires large-scale numerical simulations causes time delays. methodological improvements for acceleration are needed.

Examples of Rapid EA across the world

EA based on extreme value statistical functions

World Weather Attribution

Home | About | Analyses | News | Peer reviewed research

Extreme downpours increasing in Southern Spain as fossil fuel emissions heat the climate

Latest analyses

Heatwave

Heatwaves can be particularly dangerous to humans, and occur all over the world with increasing intensity.

Extreme rainfall

Rainfall events from a major storm or hurricane, or intense localised downpours can lead to flooding in any type of location.

The floods in eastern Spain in October 2024, which claimed over 200 lives, were made twice as likely and about 12% more intense due to human-caused CO_2 emissions from fossil fuels.

By WWA

World Weathe Attribution Website https://www.worldweatherattribution.org/

Examples of Rapid EA across the world

EA based on extreme value statistical functions

World Weather Attribution

Home | About | Analyses | News | Peer reviewed research

Climate change increased the likelihood of wildfire disaster in highly exposed Los Angeles area

Latest analyses

Heatwave

Heatwaves can be particularly dangerous to humans, and occur all over the world with increasing intensity.

Extreme rainfall

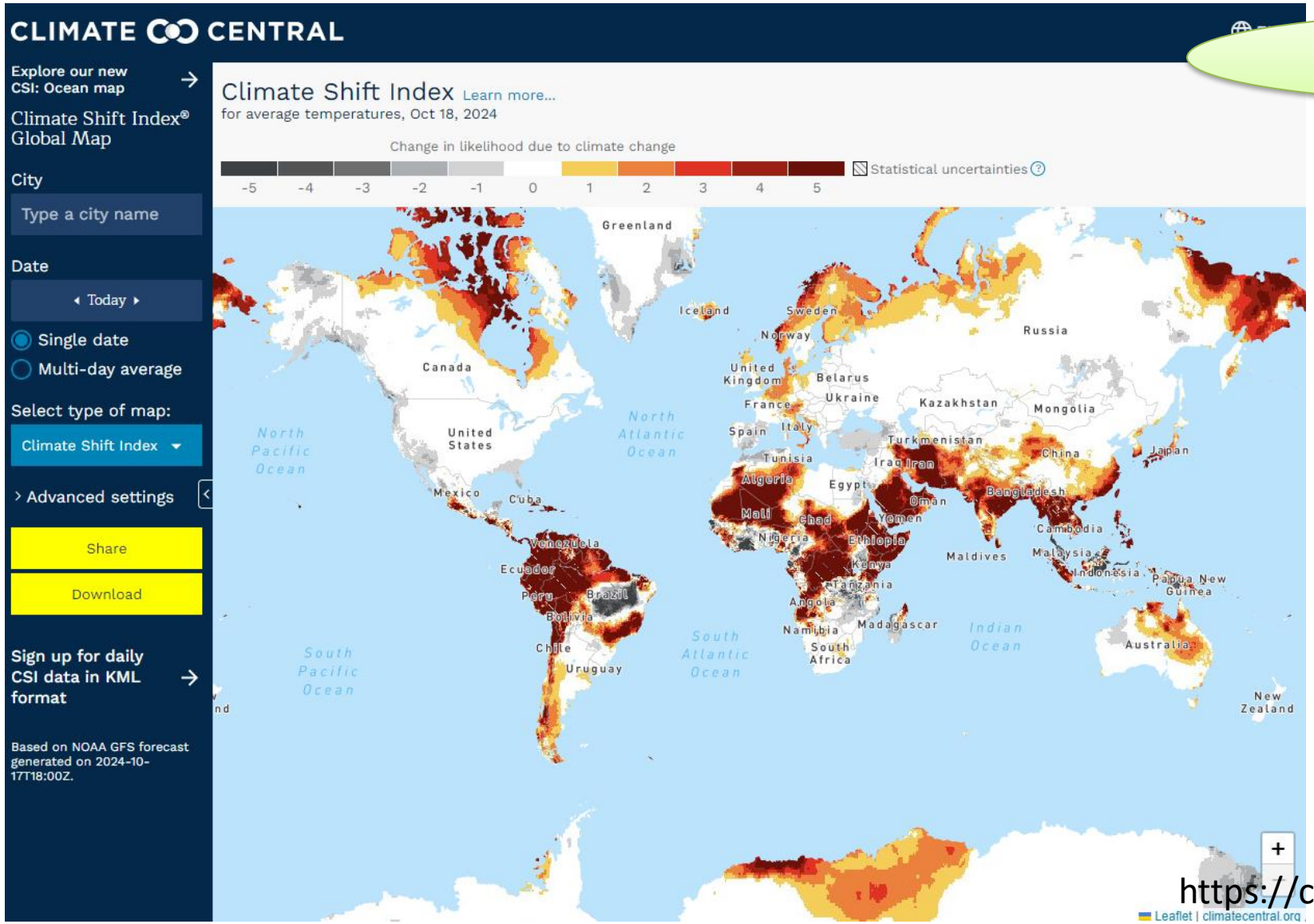
Rainfall events from a major storm or hurricane, or intense localised downpours can lead to flooding in any type of location.

- The wildfires in Los Angeles at the beginning of 2025 had their intensity increased by 6% and their occurrence probability increased by 35% due to climate change.
- In a world warmed by +2.6° C, these increases are expected to grow further by 3% and 35%, respectively.

By WWA

World Weathe Attribution website: https://www.worldweatherattribution.org/

Examples of Rapid EA across the world



Based on WWA method

Climate shift index :

By how many times has the probability of today's maximum temperature occurrence increased due to warming?

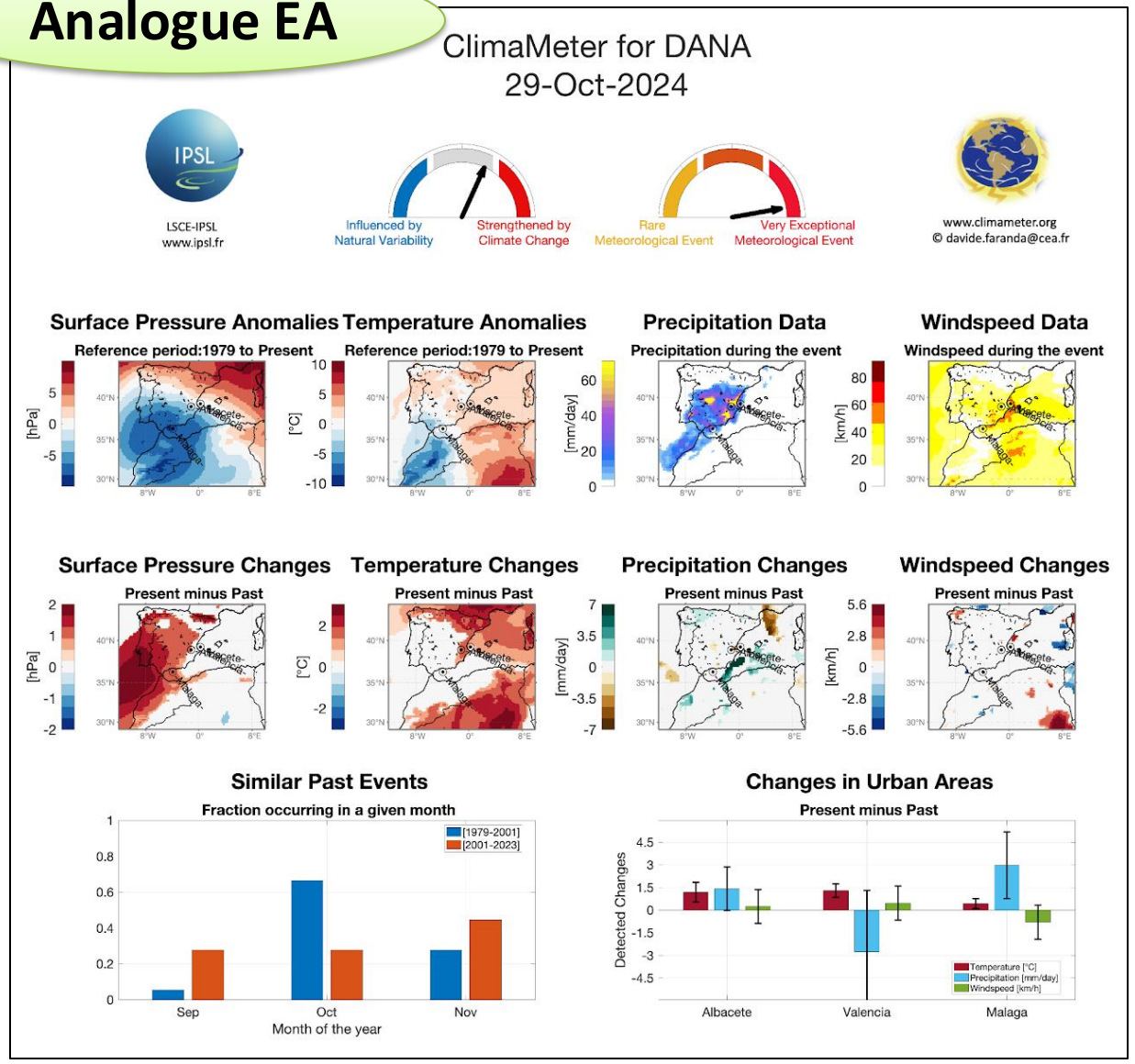
→ e.g., applied in TV weather forecast

By Climate Central

Climate Central website:
https://csi.climatecentral.org/climate-shift-index

Examples of Rapid EA across the world

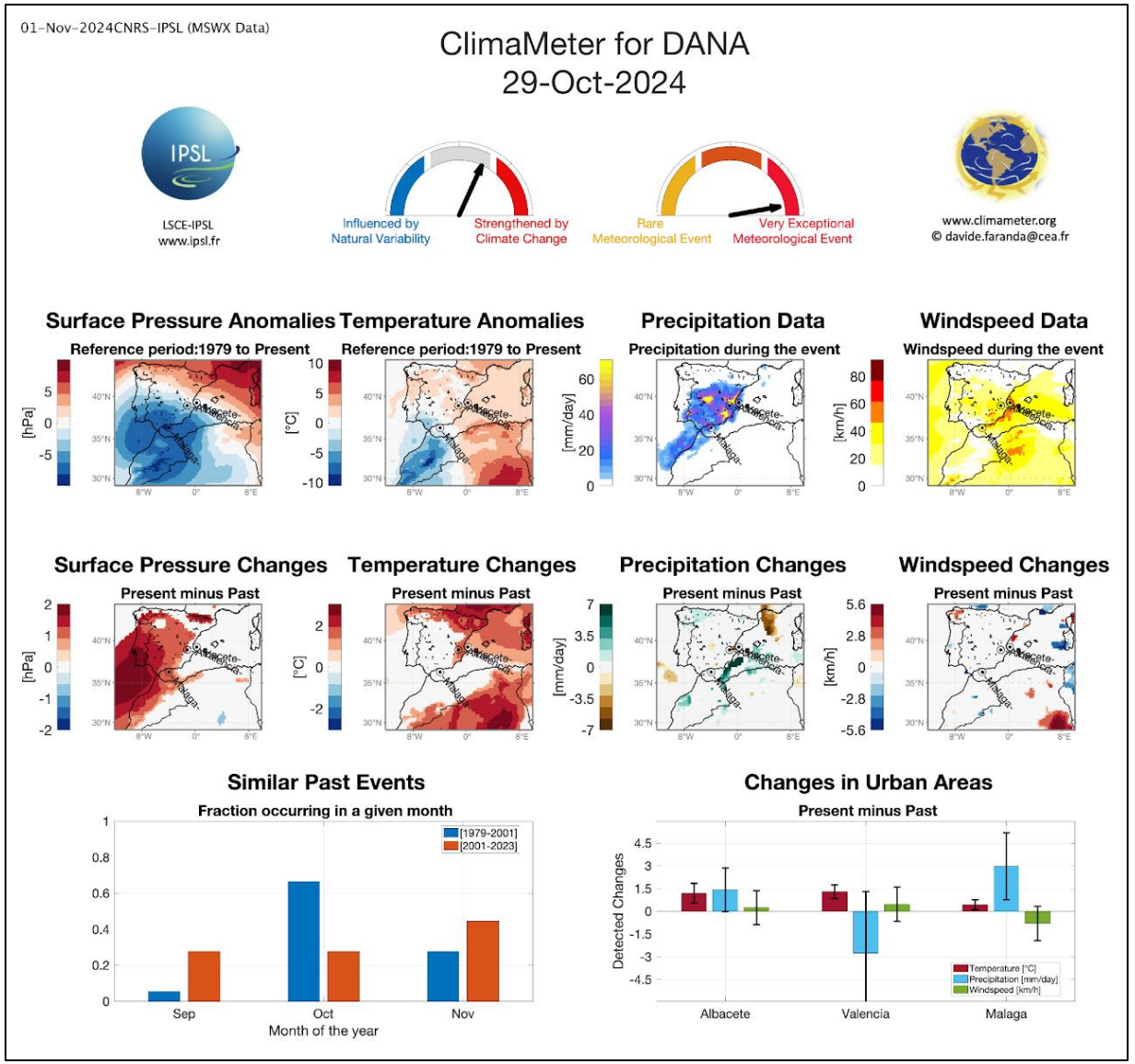
Analogue EA



ClimaMeter is an experimental rapid framework for understanding extreme weather events in a changing climate based on looking at similar past weather situations.

- Divide historical observation/reanalysis data into the past and present periods.
- The events that are similar to the target event are extracted from the two periods and compared.
- To determine how much natural variability affected the results, ClimaMeter verifies whether the AMO, PDO or ENSO phases were significantly different on average during the two sets of analogue events.

Examples of Rapid EA across the world

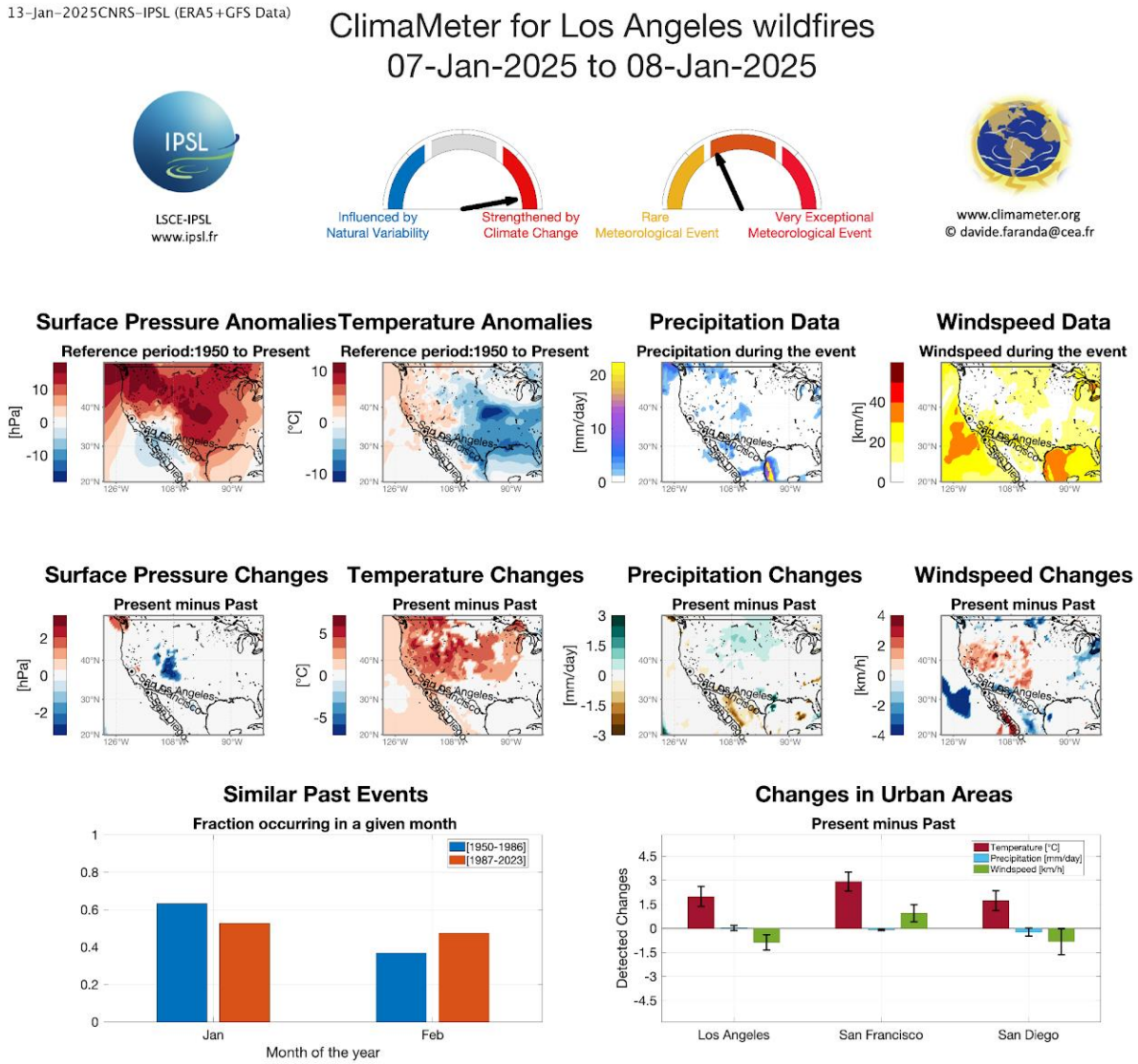


The rainfall that caused the floods in eastern Spain in October 2024 was 15% higher compared to the past. Most of this increase is believed to be influenced by human-induced global warming.

By ClimaMeter

ClimaMeter website:
https://www.climameter.org/event-dashboard

Examples of Rapid EA across the world

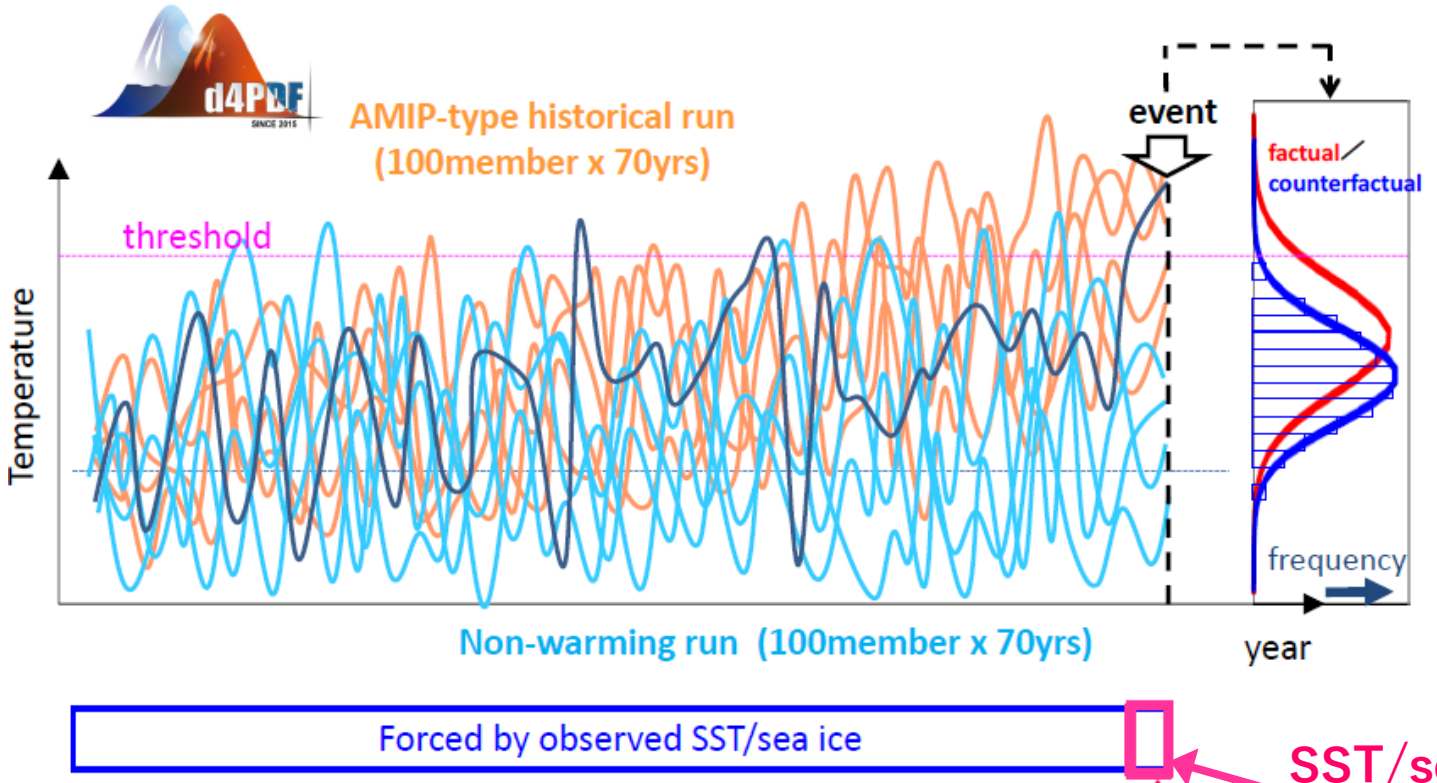


The wildfires in Los Angeles in January 2025 occurred under conditions where humidity was 15% lower and wind speed was 20% stronger compared to the past. Most of these changes are believed to be influenced by human-induced global warming.

By ClimaMeter

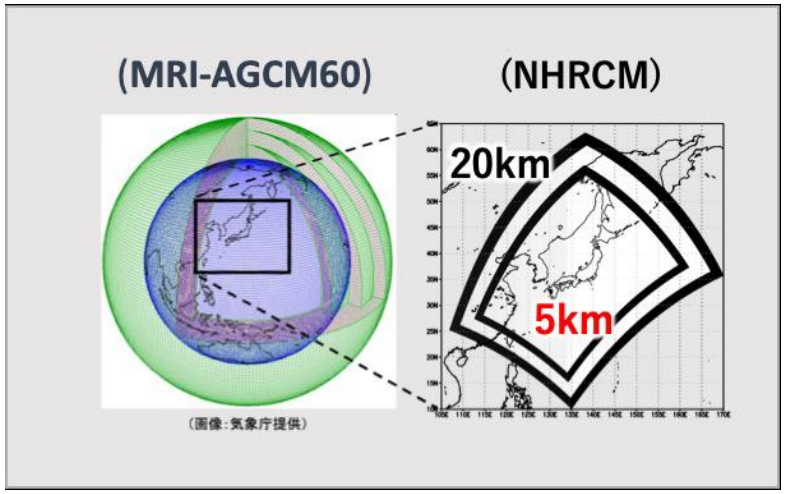
ClimaMeter website:
https://www.climameter.org/event-dashboard

Rapid EA in Japan: Predictive EA



SST/sea ice from JMA seasonal forecast
(a kind of two-tier seasonal prediction)

Dynamical downscaling
60km ➔ 20km ➔ 5km

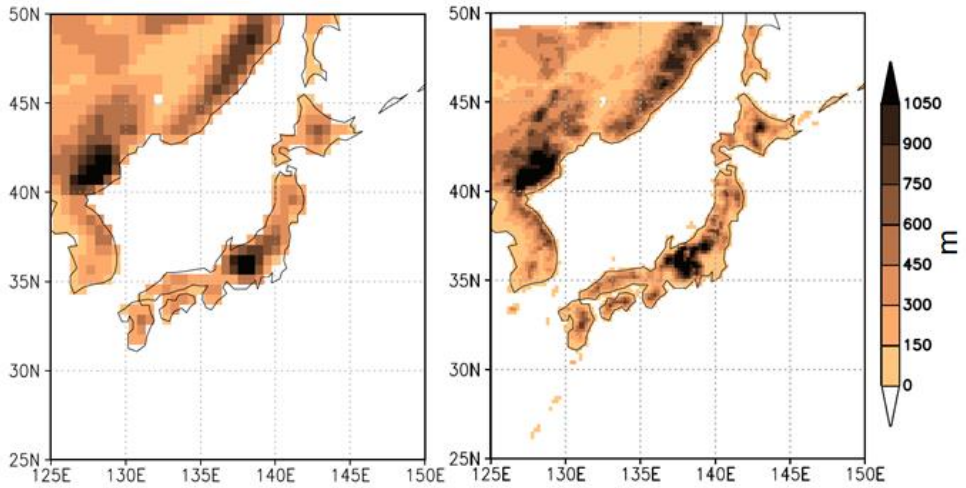


- ✓ d4PDF-type AGCM large ensemble simulations
- ✓ Utilize JMA's seasonal prediction as BCs (SST, sea ice) instead of the observation.
- ✓ Prepare high-resolution large-ensemble prediction in advance before the season of extreme events

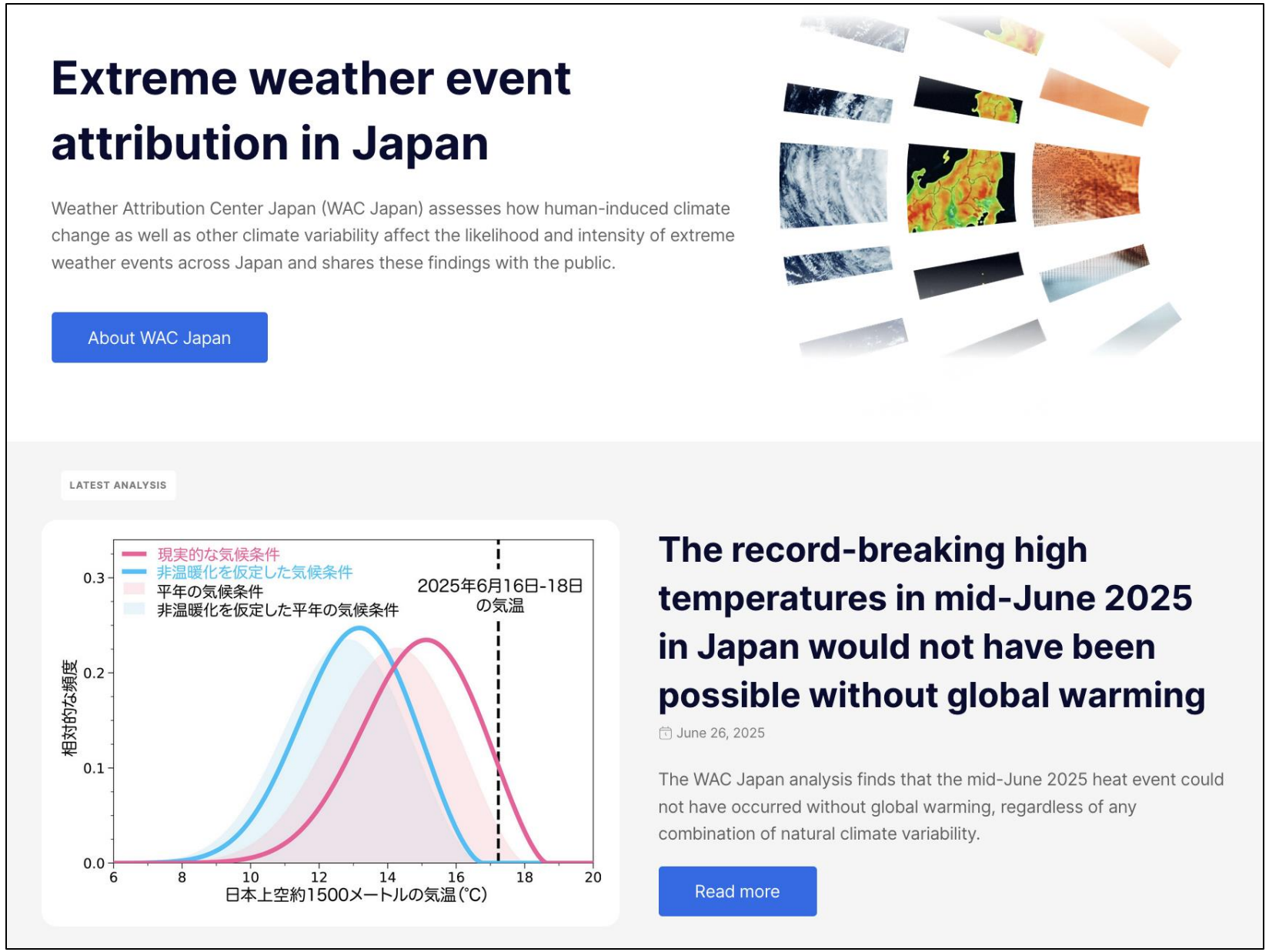
Points to note about EA in Japan

★Japan-specific issues

- **Required resolution**
  - ✓ The 20-km resolution is minimum requirement to distinguish the four main Japanese islands and climate features depend on the topography.
  - ✓ Limited available datasets: d4PDF, GFDL high-resolution ensemble runs



- **Impacts of tropical oceans**
  - ✓ Japanese extreme climate cannot be discussed without the impacts of natural variability in the tropical oceans (ENSO, Indian Ocean, etc…)
  - ✓ La Nina brings hotter summer / El Nino brings hotter winter / warmer IO brings heavy rainfall to the western Japan
  - ✓ Before reporting the impact of global warming, we have to explain what is different from the normal year by considering the impact of oceanic natural variability.
  - ✓ The unique SST pattern of each year should be considered in EA.



WAC Japan website: https://weatherattributioncenter.jp/en/

Weather Attribution Center Japan (WAC Japan)

- Rapidly releasing highly reliable analyses on our website within a few days after the occurrence of an event.
- A unique statistical method designed for the distinct meteorological features of Japan
- Currently performed manually / Automation planned for the future

Operational EA in Japan: Statistical EA

Japanese version:
PDFs for a specific year

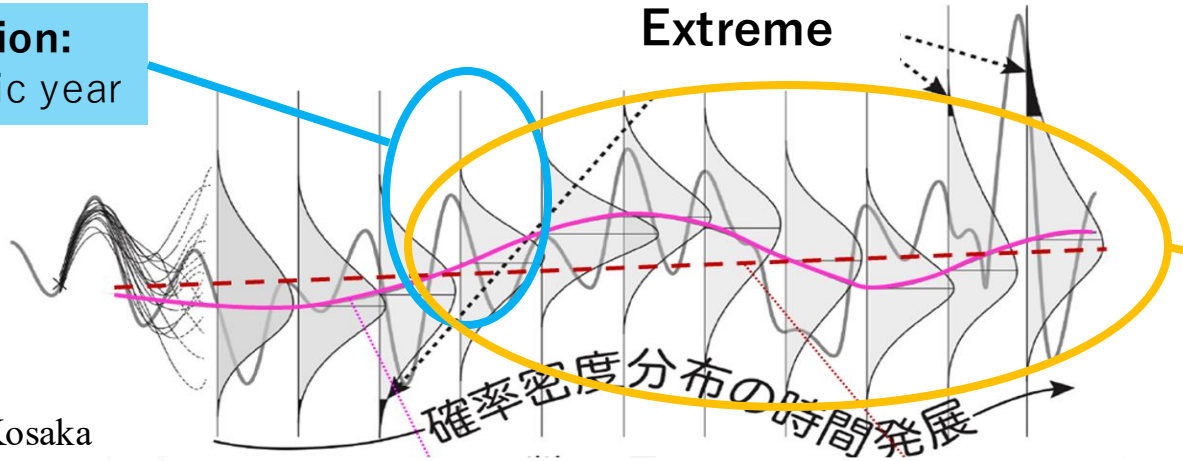


*Fig: created by Yu Kosaka

WWA-like method:
PDFs averaged for several years

Gaussian

$$P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

GEV

$$P(x) = \exp\left[-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{-1/\xi}\right]$$

μ : location parameter (~mean)
σ : scale parameter (~standard deviation)
ξ : shape parameter (~skewness)

※ $\xi = 0$ of GEV: **Gumbel distribution**

Estimate parameters μ, σ, ξ as a function of the specific SST pattern

Takahashi et al. (2025)

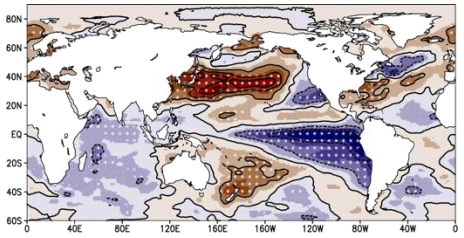
Operational EA in Japan: Statistical EA

□ STEP1
Estimate the impact of oceanic natural variability on μ and σ using non-warming large ensemble experiment

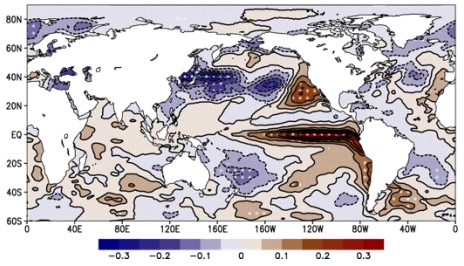
□ STEP2
Estimate the impact of anthropogenic warming on $\Delta\mu$ and $\Delta\sigma$ from the difference between HIST and Non-warming simulations.

Temporal regression of SST on μ(t) and σ(t) (Non-warming run)

μ



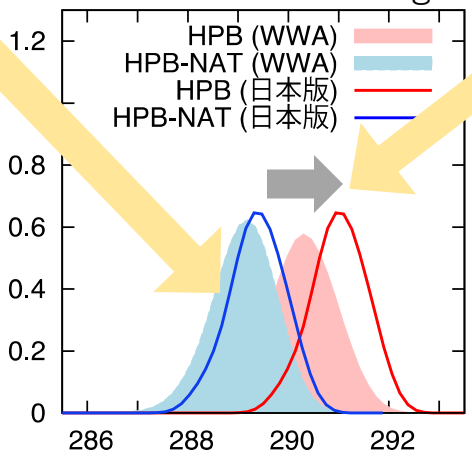
σ



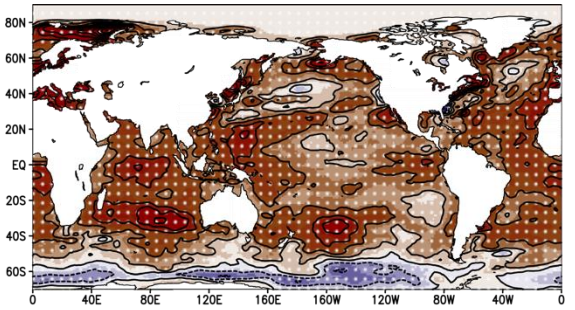
Reconstruct the PDF using $\mu(t_{target})$ and $\sigma(t_{target})$

Shift PDF with $\Delta\mu$ ($\Delta\sigma$)

※Image



Regression of SST on $\Delta\mu$(t) (5-year running mean)



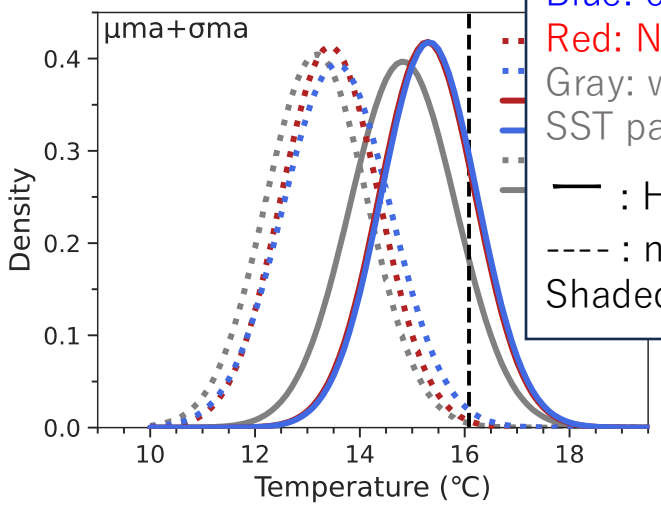
SST warming pattern related to Japanese temperature

Takahashi et al. (2025)

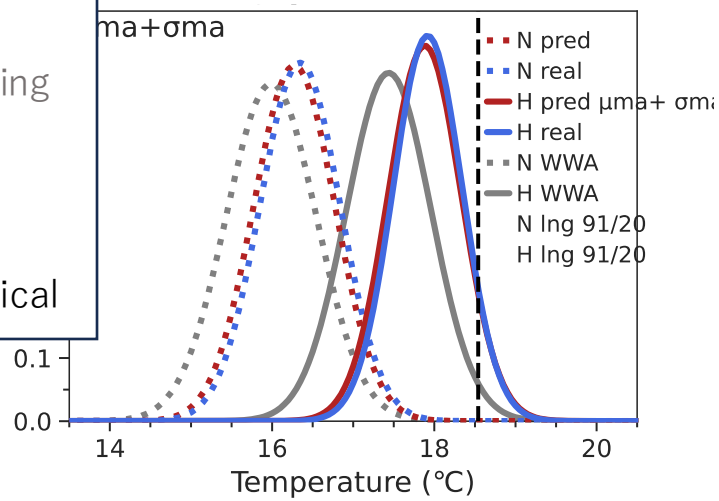
Operational EA in Japan: Statistical EA

Hot extreme events in Japan

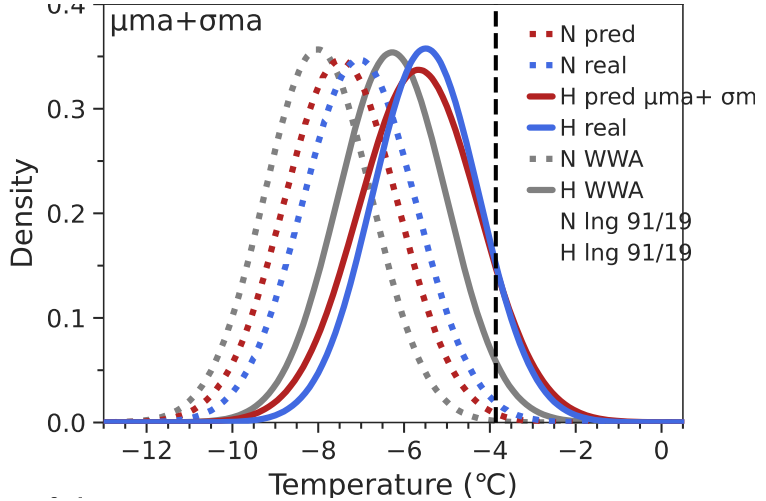
2022 early summer



July 2018



December 2019-February 2020 hot winter



Probability exceeding a threshold

	HIST	NAT
d4PDF-base	20.25%	0.69%
New method	**19.07**	**0.22**
w/o considering SST pattern	10.58	0.14

HIST	NAT
7.2%	0%
7.1	**0**
1.73	0

HIST	NAT
9.46%	0.8%
9.95	**0.32**
2.86	0.05

Takahashi et al. (2025)

Various EA methods to date

Various types of EA

Probabilistic (risk-based) EA

Attribution for likelihood. Usually based on AGCM/CGCM large ensemble simulations. LESFMIP can be also used.

Storyline EA

Attribution for severity. Usually based on historical and pseudo-non-warming simulations using high-resolution regional climate models.

Statistical EA

A kind of probabilistic (risk-based) EA but based on extreme value statistical functions obtained from the observation or existing simulations. Adopted by **WWA**, **Climate Central**, **WAC Japan** etc.

Analogue EA

Attribution for both likelihood and severity. Find and compare analogues from the observation or existing simulations. Adopted by **ClimaMeter**.

Conditional EA

Attribution for dynamical fields (extreme circulation). Utilize initialized large ensemble simulations.

EA for record-shuttering events

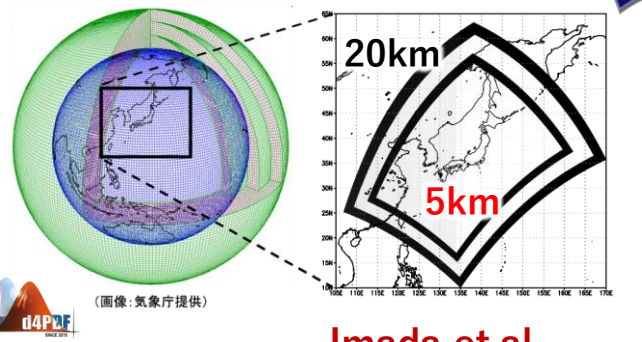
e.g., Ensemble boosting method: Select a subsamples in which a causal circulation field is likely to develop and increase the number of members by adding the initial perturbations. / **UNSEEN project by ECMWF**

Multiple EA systems in Japan

Imada et al.

Risk-based EA with extend d4PDF

Global model (MRI-AGCM60) | Regional model (NHRCM)

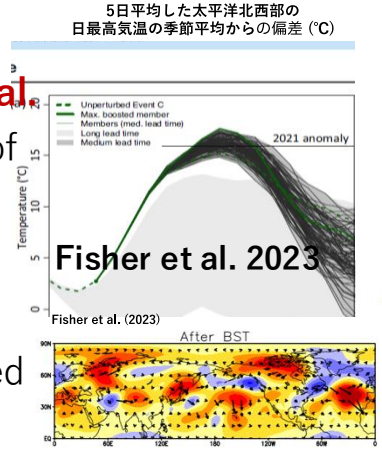


Imada et al.

Ensemble boosting System for dynamical EA (trial)

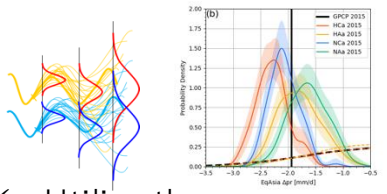
d4PDF x Ensemble boosting Higuchi et al.

- ✓ Increase the number of members which promise the growth of a specific circulation pattern
- ✓ Capture unprecedented events



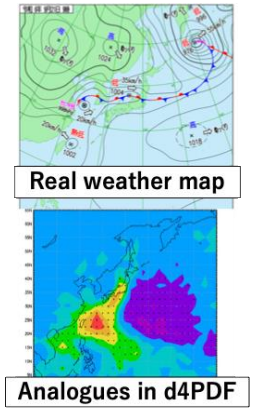
Coupled EA

Hasegawa et al.



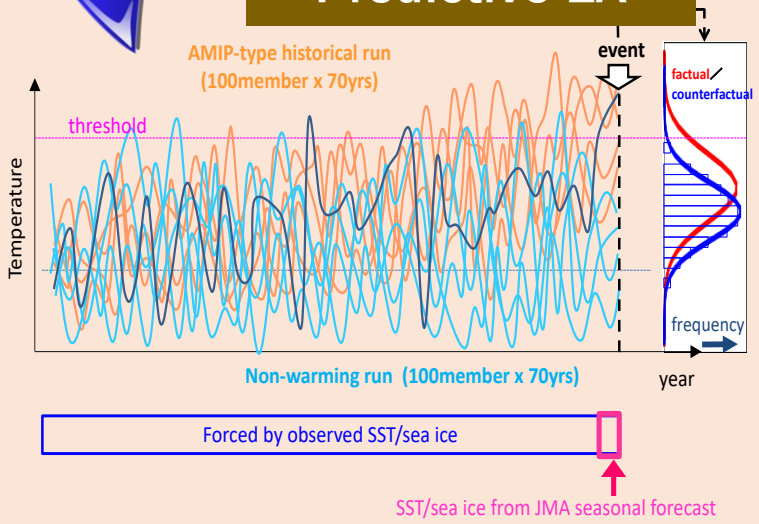
- ✓ Utilize the assimilation system of seasonal forecasts.
- ✓ Consider the effects of air-sea interaction

Analogue EA



Rapid EA

Predictive EA

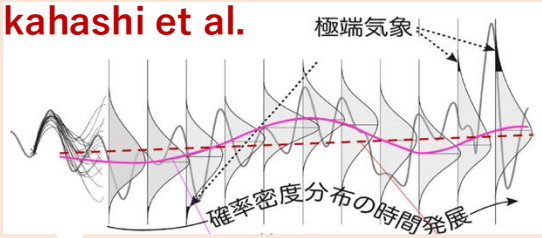


Imada et al.

Lower boundary condition is replaced by seasonal forecasted SST and sea ice.

Statistical EA

Takahashi et al.



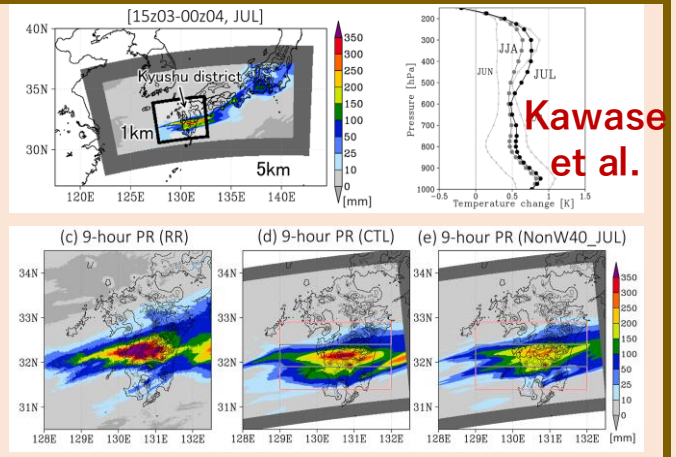
Gaussian $P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$

GEV $P(x) = \exp\left[-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{-1/\xi}\right]$

μ(t), σ(t), ξ(t)をd4PDFから予め推定

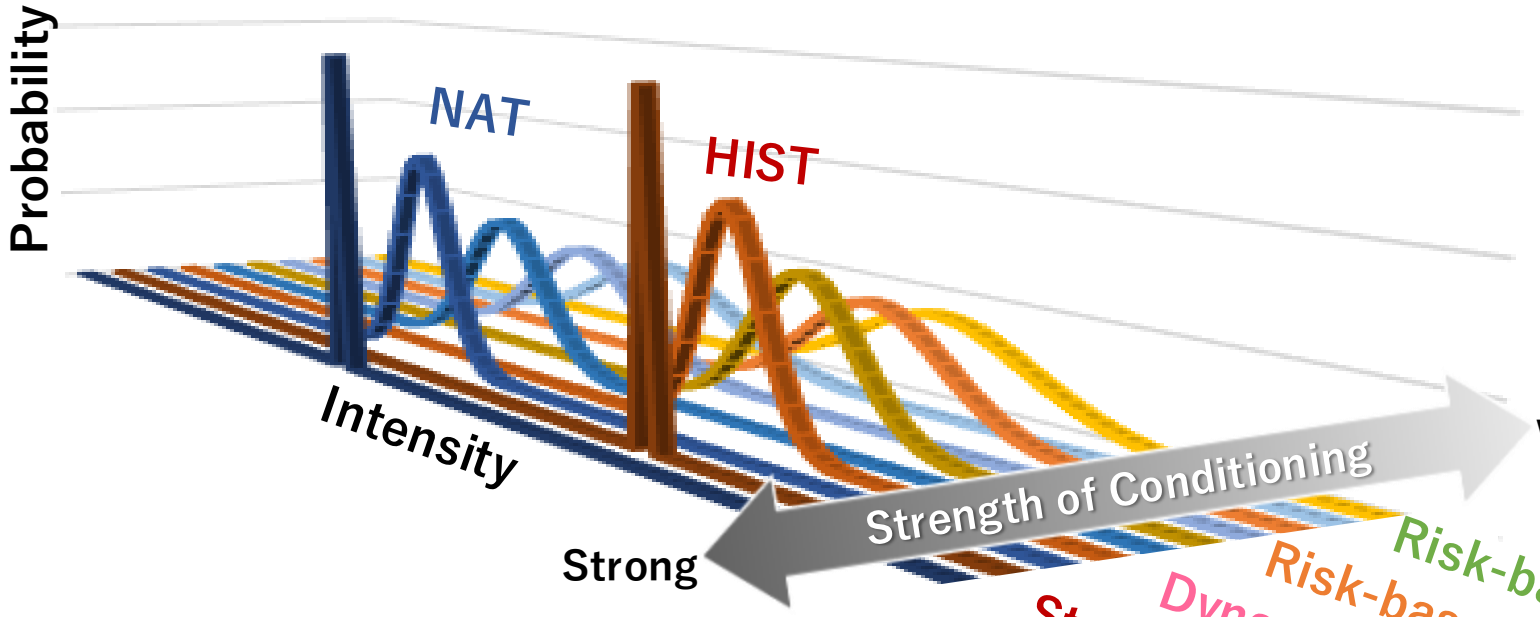
Storyline EA（pseudo-non-warming experiment）

Kawase et al.



Seamless Event Attribution

～ from risk-based EA to storyline EA



Condition: SST and sea ice nearly identical to real conditions

Condition: Anthropogenic & Natural forcing

Risk-based EA by CGCM (D&A)

Risk-based EA by AGCM

Dynamical EA by initialized ensemble simulation

Storyline EA by RCM

Condition: atmospheric circulation nearly identical to real conditions

Condition: initial atmospheric circulation nearly identical to real conditions

The choice of methodology should be based on a clear understanding of which background conditions are assumed for the extreme event of interest, and which aspects are to be treated as the plausible range of variability.

Summary ～Next step?

- Event Attribution has the potential to support and promote national climate policies, both in mitigation and adaptation.
- Wider variety of EA methods
  - In addition to the original risk-based and storyline approaches, operational methods conducted by WWA, ClimateCentral, ClimaMeter, BoM, WAC Japan, etc…
- How to evaluate the uncertainty induced by different methods?
- Each method may focus on different aspects of extreme events and provide different types of information. How can we synthesize these insights and deliver them effectively to users?

➢ Multiple methods to one common extreme event