The impact of climate change on the extreme ocean warming events observed in Japan's marginal seas for 1982-2022

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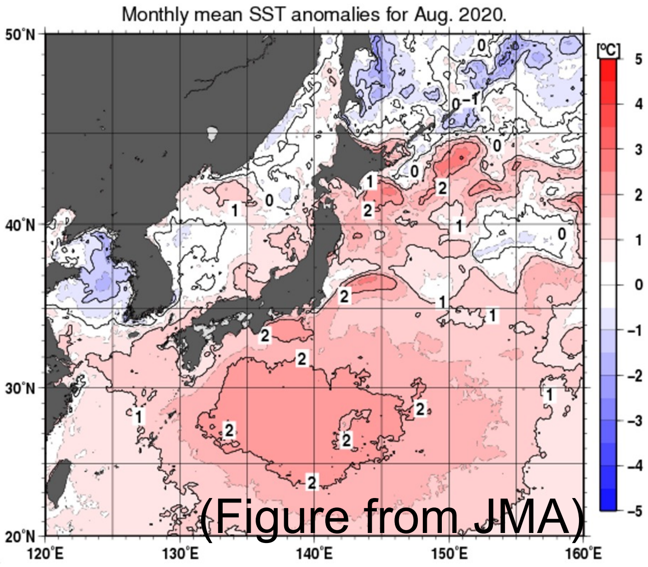

(Figure from JMA)


Geophysical Research Letters

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Key Points:
- The contribution of climate change to discrete extreme ocean warming (EOW) from January 1982 through

The Contribution of Climate Change to Increasing Extreme Ocean Warming Around Japan

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(results updated from Hayashi et al. 2022 GRL)

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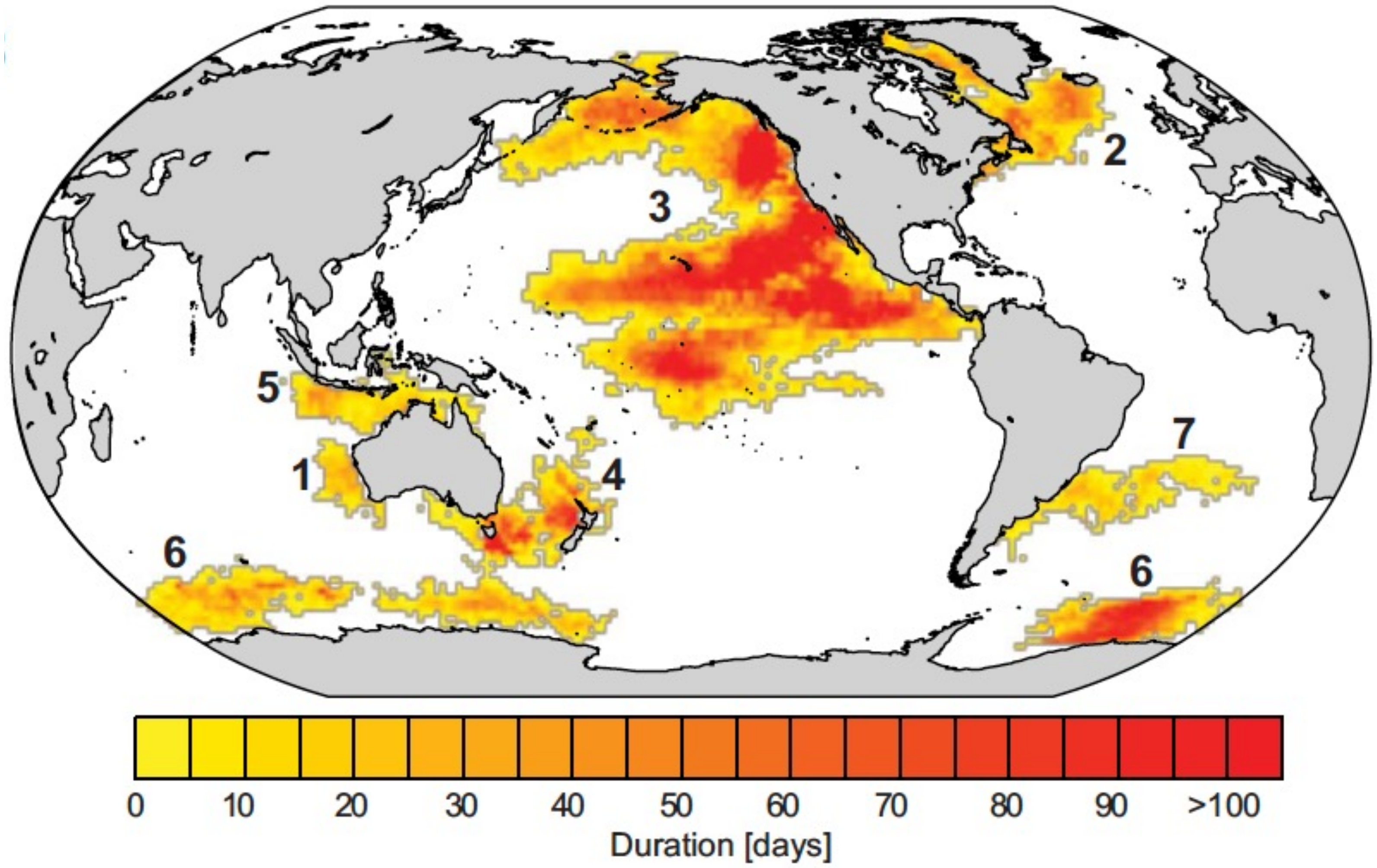
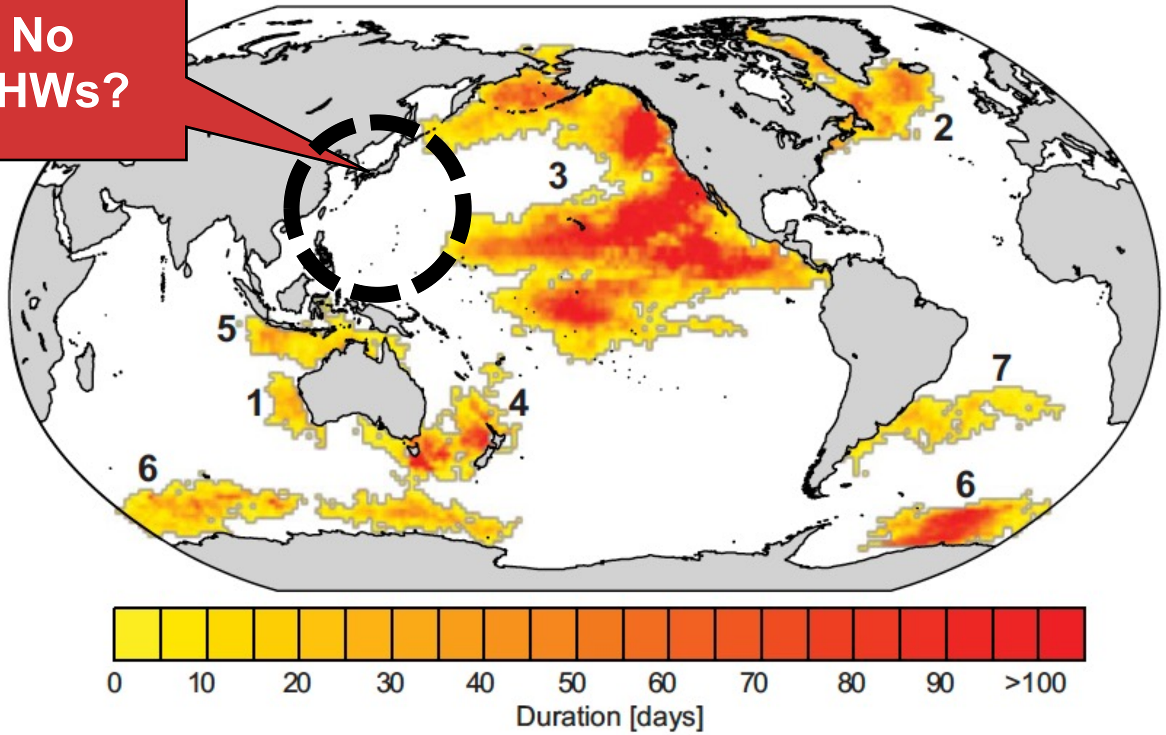


(Laufkötter et al. 2020, *Science*)

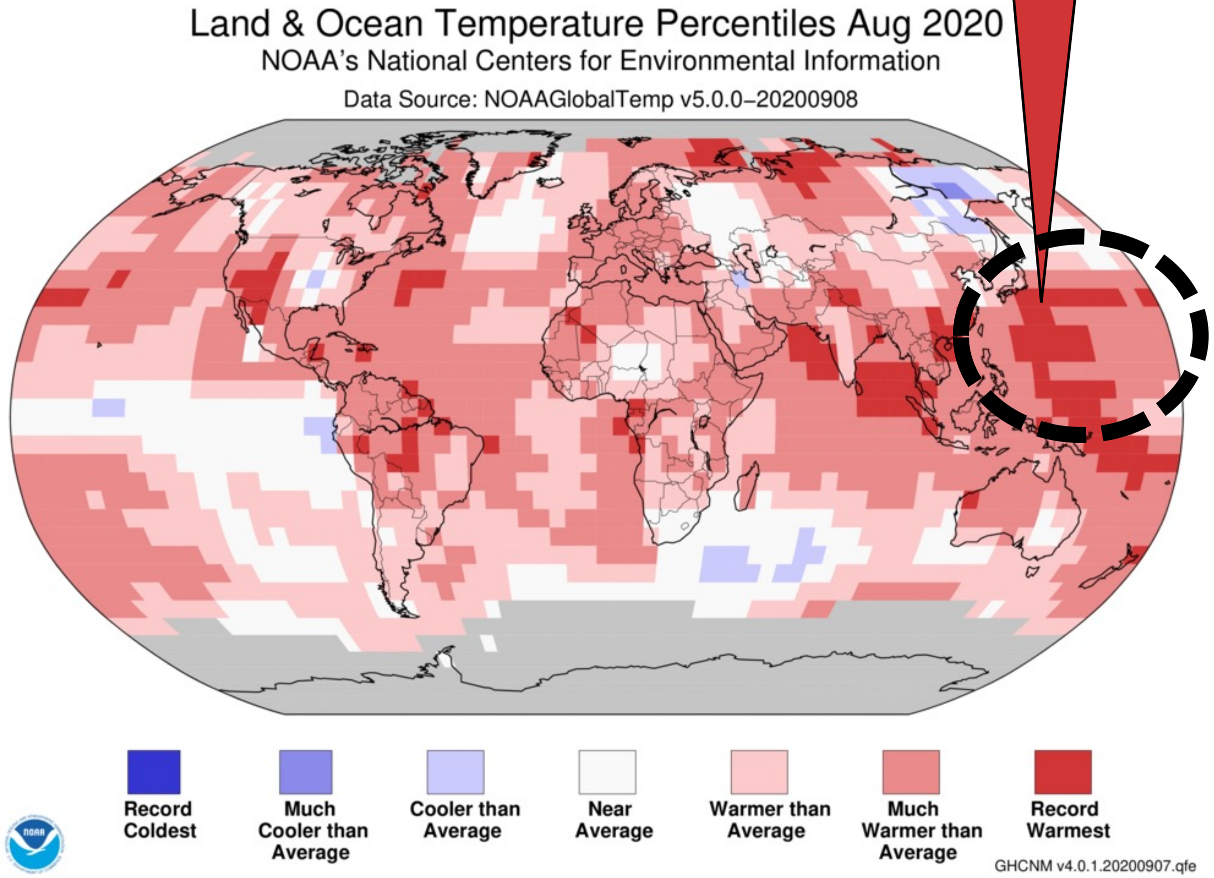
Marine heatwaves (MHWs)

—periods of extremely high ocean temperatures in specific regions—

No MHWs?



Record Warmest



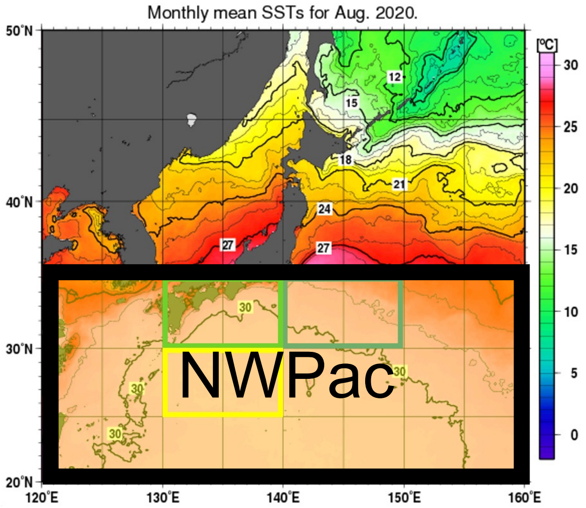
"the occurrence probabilities of the duration, intensity, and cumulative intensity of most documented, large, and impactful MHWs have increased more than 20-fold as a result of anthropogenic climate change."

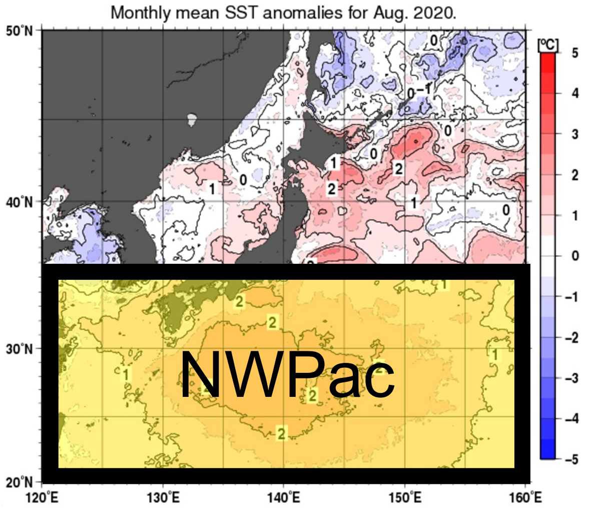
(Laufkötter et al. 2020, *Science*)

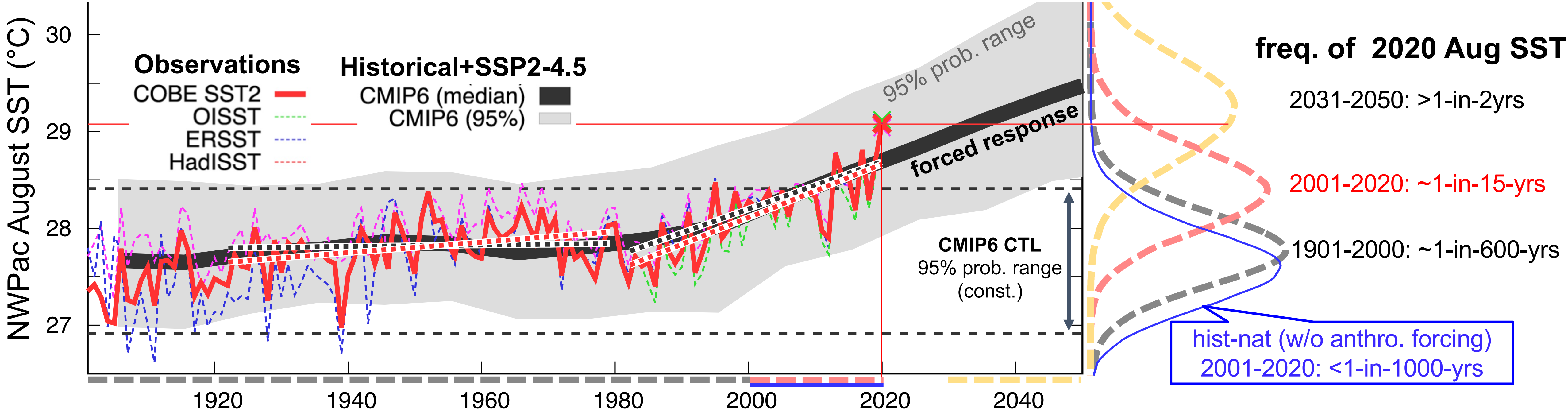
August 2020 northwestern Pacific record-high SST

Previous study (Hayashi et al. 2021, GRL) showed that

- August 2020 set the record high SST in the northwestern Pacific (NWPac) since the 20th century
- CMIP6 climate models well reproduce the long-term changes in the NWPac SST
- Anthropogenic forcing increased the occurrence frequency of such SST from <1-in-1000yr to 1-in-15yr

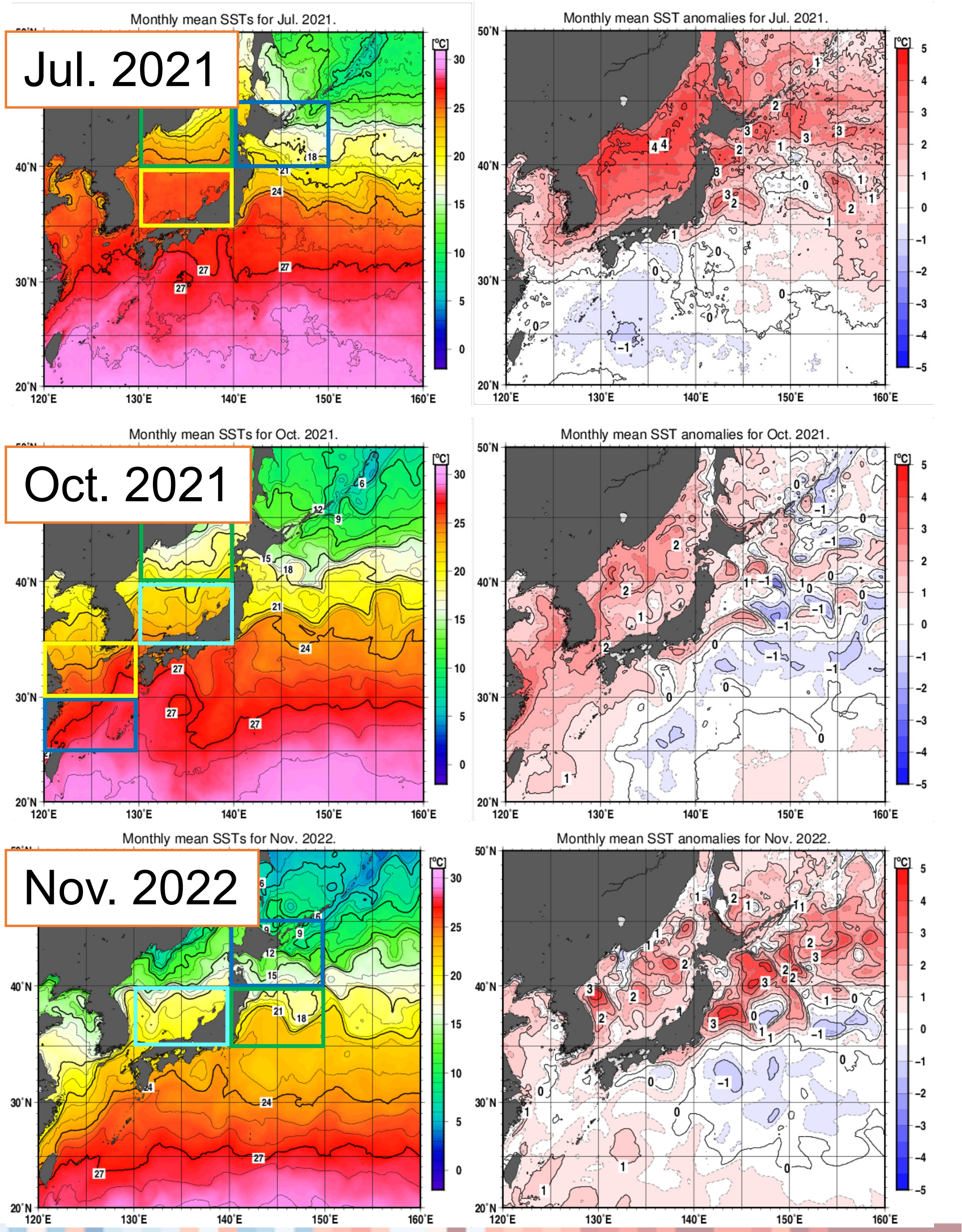






Record warmest SSTs around Japan

- Even after 2020, extremely high SSTs were observed frequently near Japan.
- The number of unprecedentedly warm SSTs is increasing but the impacts of anthropogenic global warming on these extreme SST events have not been quantified yet.
- A comprehensive analysis of long-term data in different areas and seasons around Japan is needed.



(JMA reports, 臨時診断表)

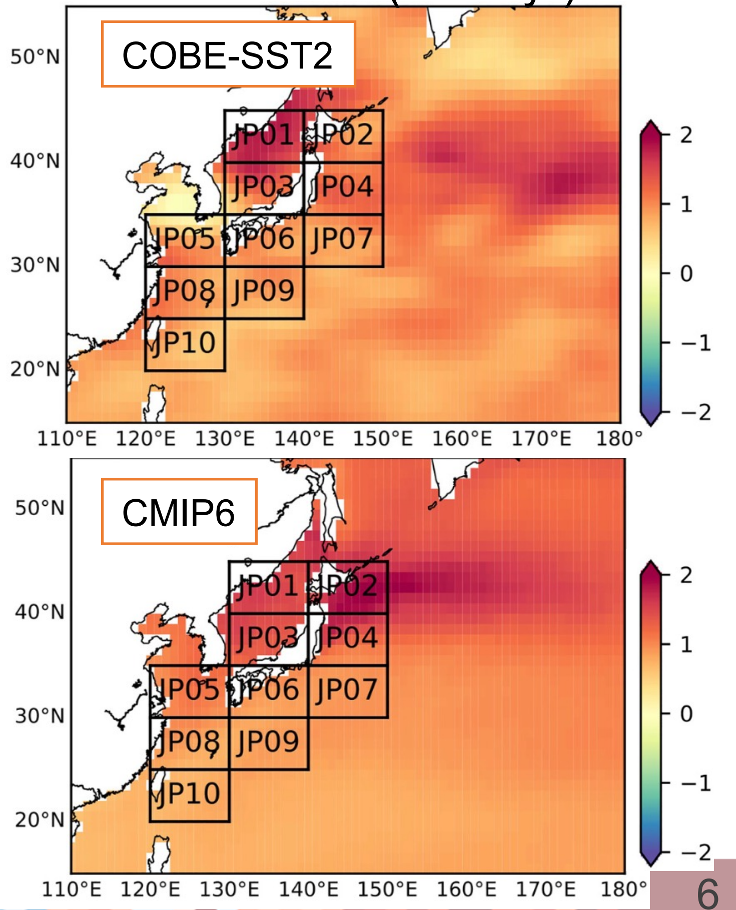
Objective & Data

- Here, we applied Hayashi et al. (2021)'s method **to investigate monthly Extreme Ocean Warming (EOW) events around Japan in each calendar month from 1982 to 2022** by focusing on the 10 operational monitoring areas (defined by the JMA).

- **Observational SST data: COBE-SST2**
  - For comparison: OISST v2, HadISST v1.1, ERSST v5
- **Model SST data: 24 CMIP6 climate models**
  - Factual world: HIST/SSP2 runs (ssp245, 1850-2100)
  - Counter-factual: CTL runs (preindustrial, 200 years)
  - Bias correction based on 1951-2000 mean

- Analyzed period: Jan 1982 – Dec 2022 (updated)
- Analyzed areas: JP01…JP10, except for JP02

SST trend (°C/40yr)

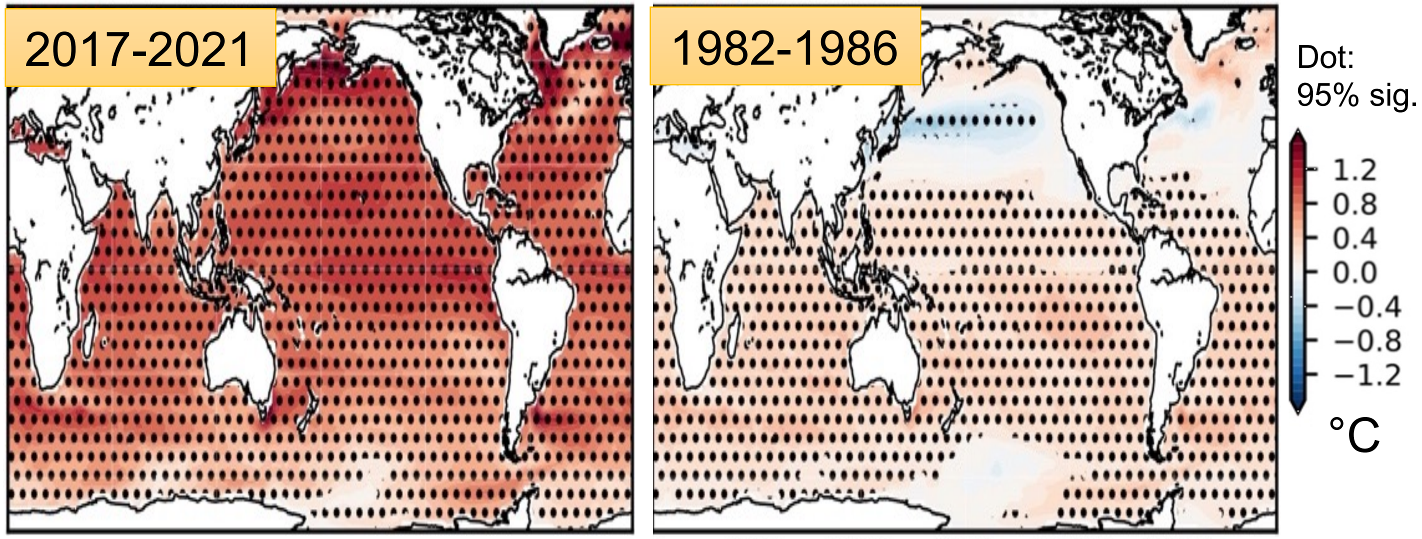


(Hayashi et al. 2022)

Global aspects of SST changes

- Globally warming anomaly in 2017-2021
- N. Pacific cooling anomaly in 1982-1986
  - Attributable to increased aerosol forcing
  - Intensified in boreal summer (Zhang et al. 2022)

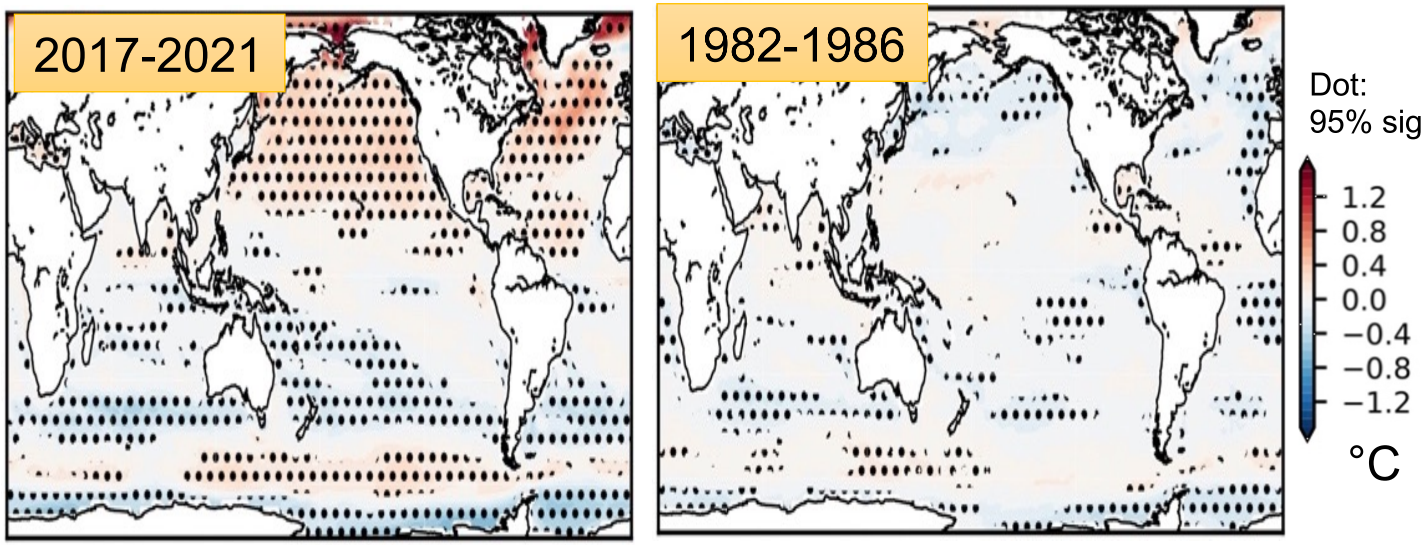
Annual SST anomaly relative to piControl (CMIP6 mean)



Robust warming seasonality in 2017-2021

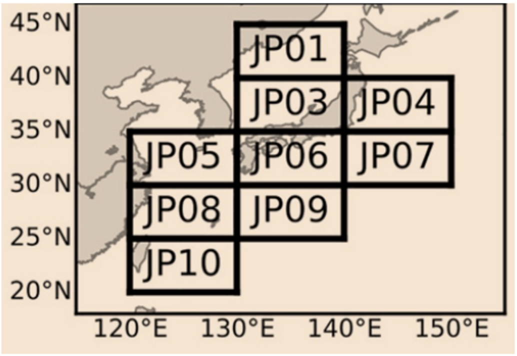
- N.H. warms faster in summer-autumn
  - Consistent w/ increased inter-hemispheric asymmetry after the 1980s due to land-sea contrast, Southern Ocean heat uptake, etc. in response to GHG warming (Friedman et al. 2013, 2020)
  - Potentially related to higher southward atmospheric energy transport in late summer-autumn, shifting Hadley cell and ITCZ to the north (Song et al. 2018)

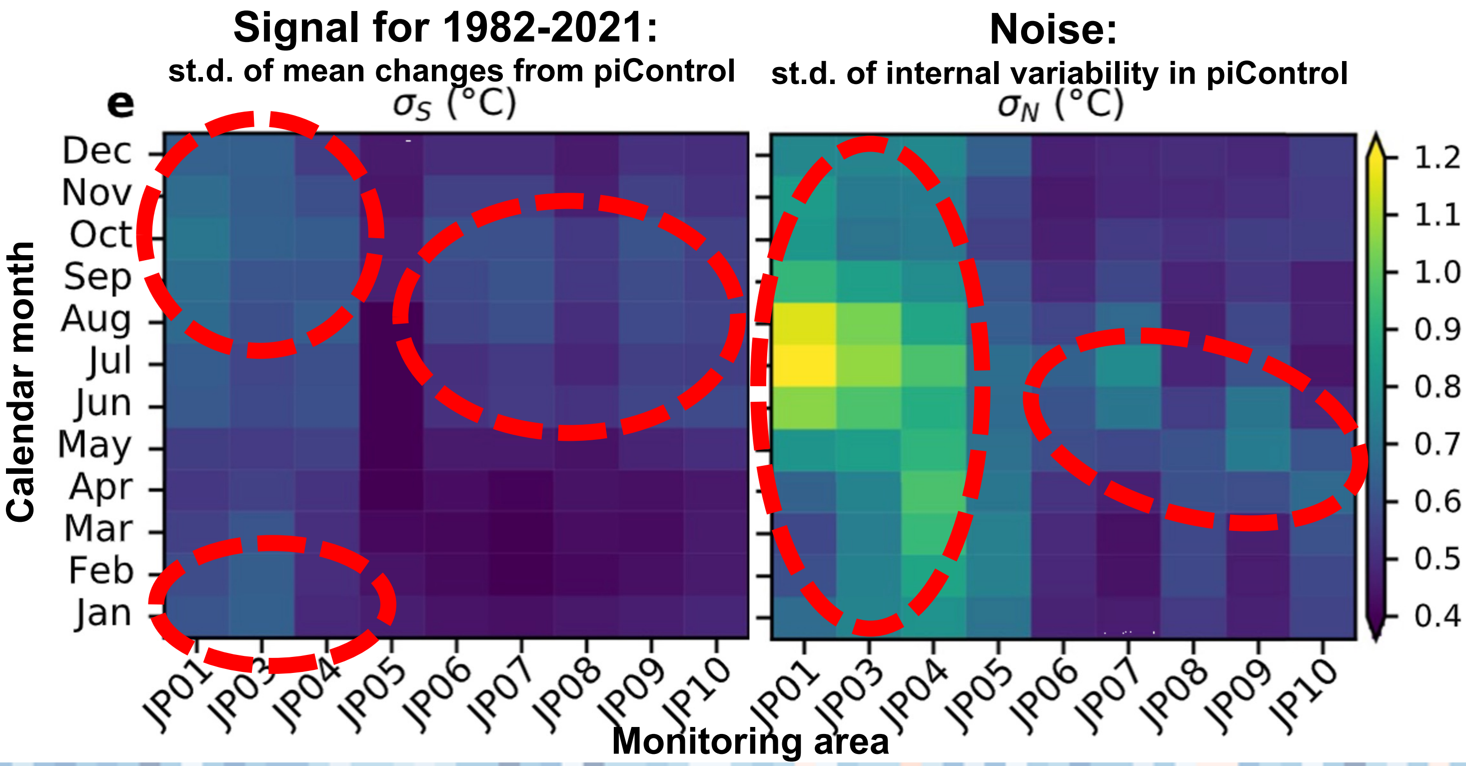
Seasonal diff. of SST anomaly (JJASON minus DJFMAM)

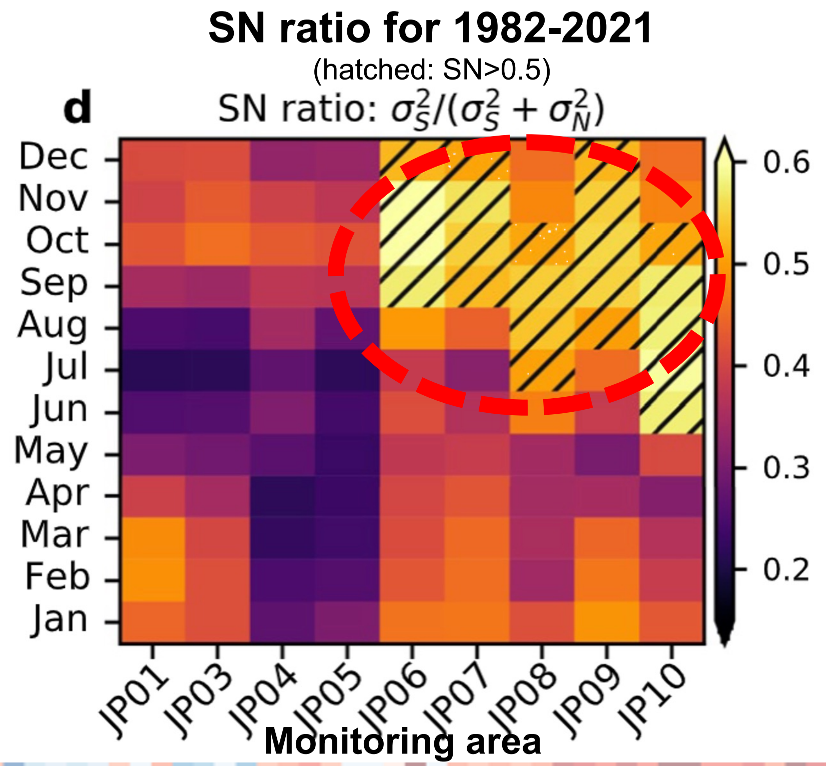


Global warming signal: regionality & seasonality

- Signal (σ_S): higher in boreal summer-autumn
  - At northern Japan, signal is reduced in summer
- Noise (σ_N): higher in summer, especially at northern Japan
  - At southern Japan, noise is higher in spring-early summer
- **Signal-to-Noise (SN) ratio=$\sigma_S^2/(\sigma_S^2+\sigma_N^2)$: >0.5 in late summer-early winter at southern Japan**







Extreme Ocean Warming (EOW) event attribution

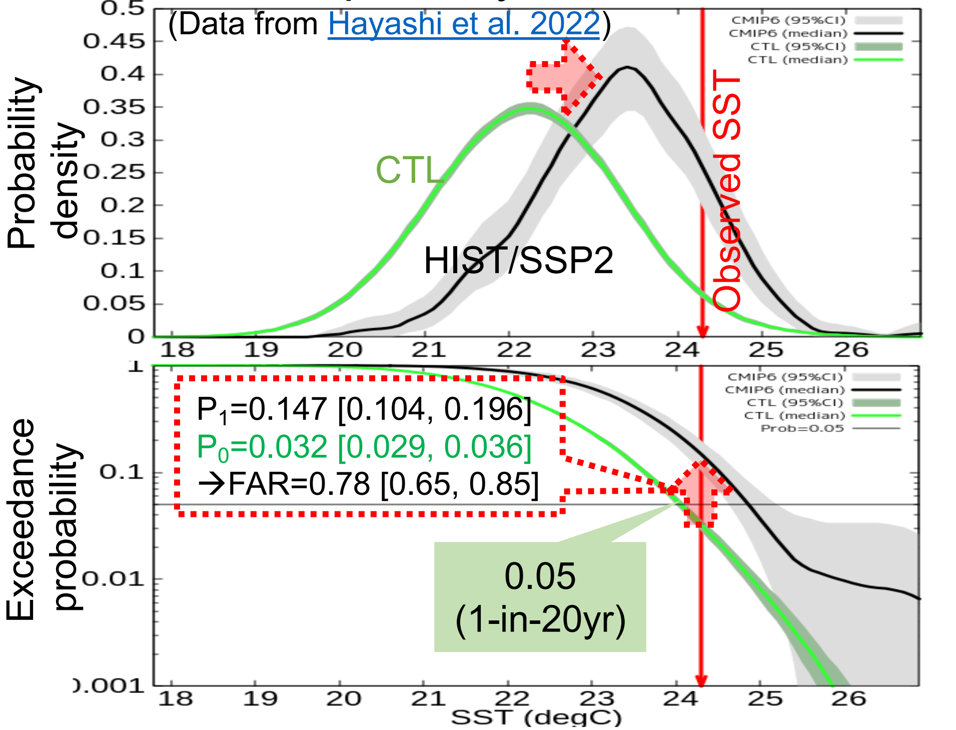
- *Calculate* **the exceedance prob of observed SST in each month/year**
  - ○ Probability w/o global warming (P_0)
    - CTL, 200 yrs
  - ○ Probability w/ global warming (P_1)
    - HIST/SSP2, target-year ±2yrs
- *Estimate* **the Fraction of Attributable Risks**

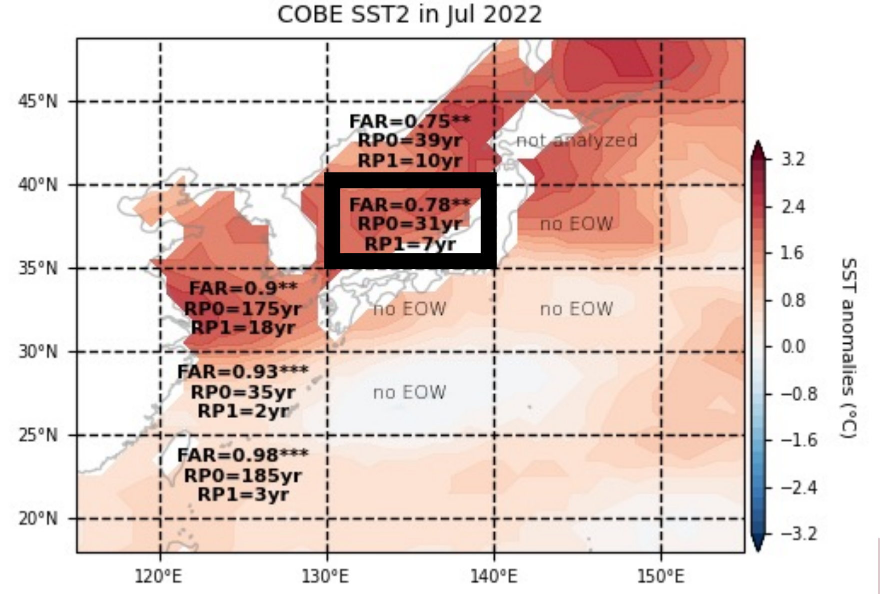
$$FAR = 1 - P_0/P_1$$

  - ○ FAR=0.5: doubled due to climate change
  - ○ FAR=0.9: increased ten-fold due to climate change
- *Identify* **EOW events observed in 1982-2022**
  - ○ Threshold: Observed area-averaged monthly SST less than “1-in-20yr” w/o global warming (P_0≤0.05/yr)
- *Discuss* **the long-term change of FAR in EOW events**

*95% C.I. of P_0 & P_1 by 1000 times bootstrapping

Example: July 2022 in JP03





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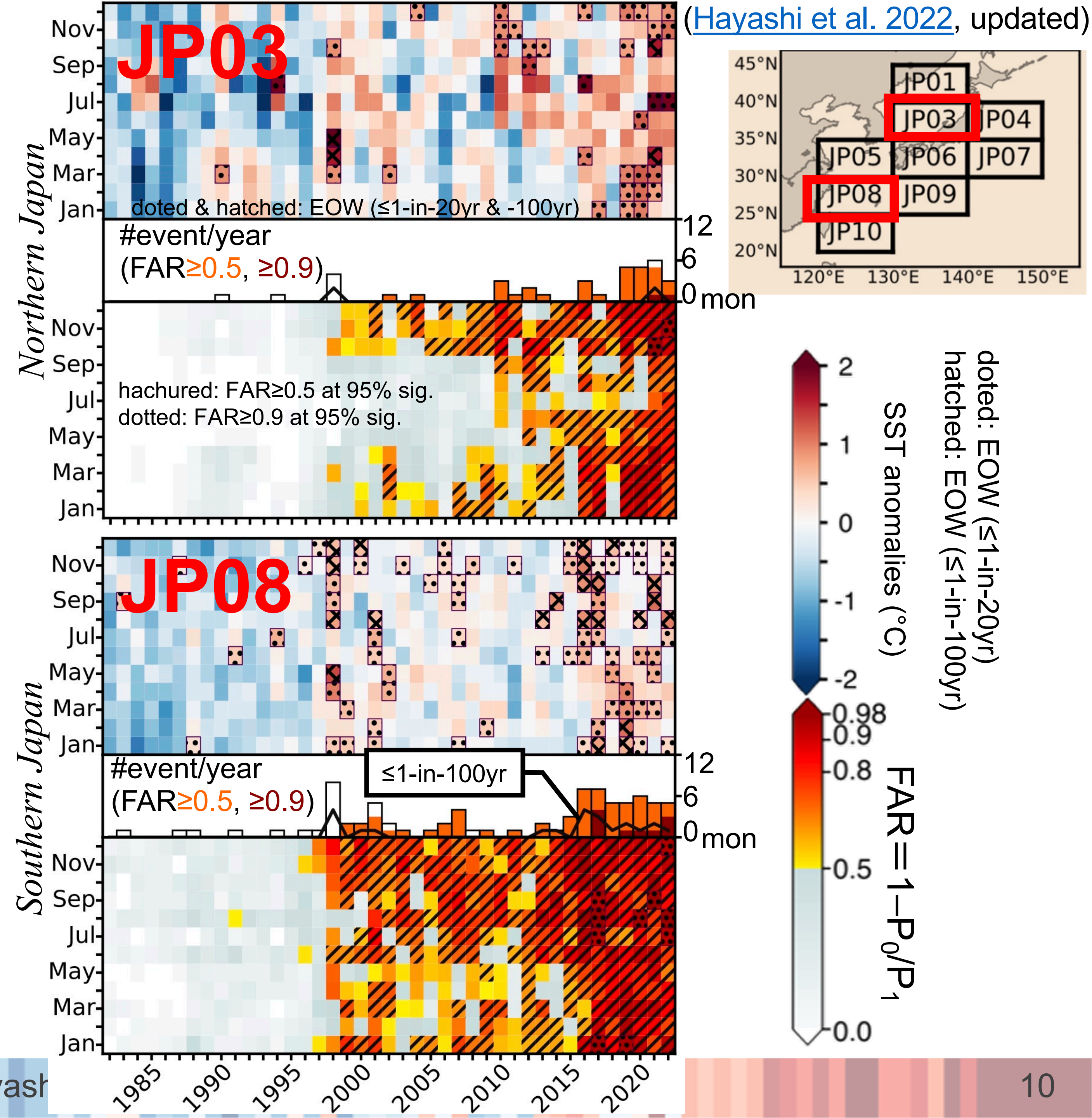
COBE SST2 retrieved from NEAR-GOOS RRTDB on 07 Sep, 2022

EOW events & FAR

- #events gradually increased
  - More frequent around 1998 and after 2010s
  - #events higher in southern Japan
  - “1-in-100yr” events increased since ~2015
- FAR≥0.5 significantly for most EOW events since 2000s
  - In southern Japan, #events of FAR≥0.9 increased since ~2015
  - The contribution of global warming to EOW events is yet less significant around 1998

(Hayashi et al. 2022, updated)

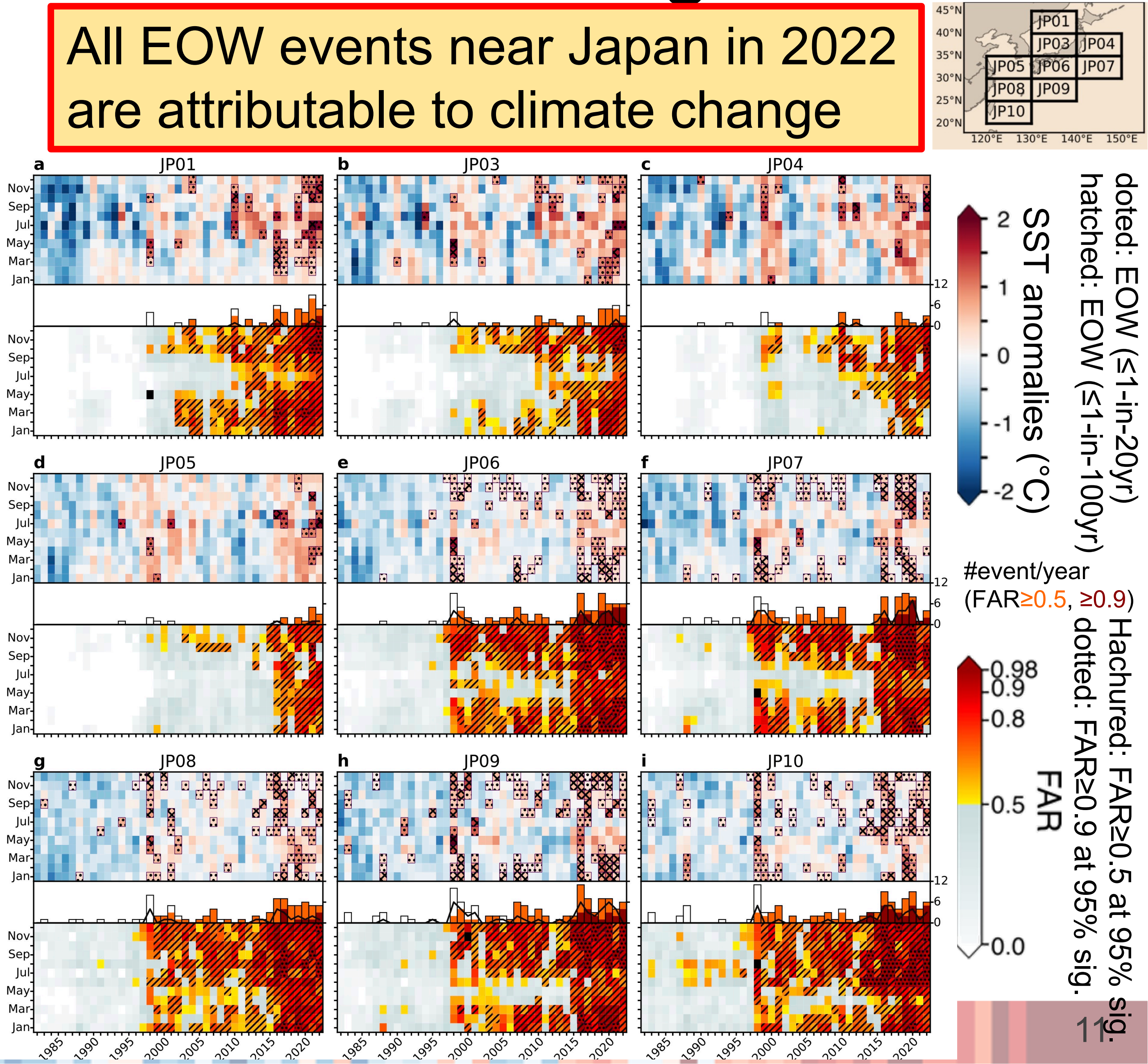


(Hayashi et al. 2022, updated)

EOW events & FAR in all the 9 monitoring areas

- #events gradually increased
  - More frequent around 1998 and after 2010s
  - #events higher in southern Japan
  - “1-in-100yr” events increased since ~2015
- FAR≥0.5 significantly for most EOW events since 2000s
  - In southern Japan, #events of FAR≥0.9 increased since ~2015
  - The contribution of global warming to EOW events is yet less significant around 1998

All EOW events near Japan in 2022 are attributable to climate change

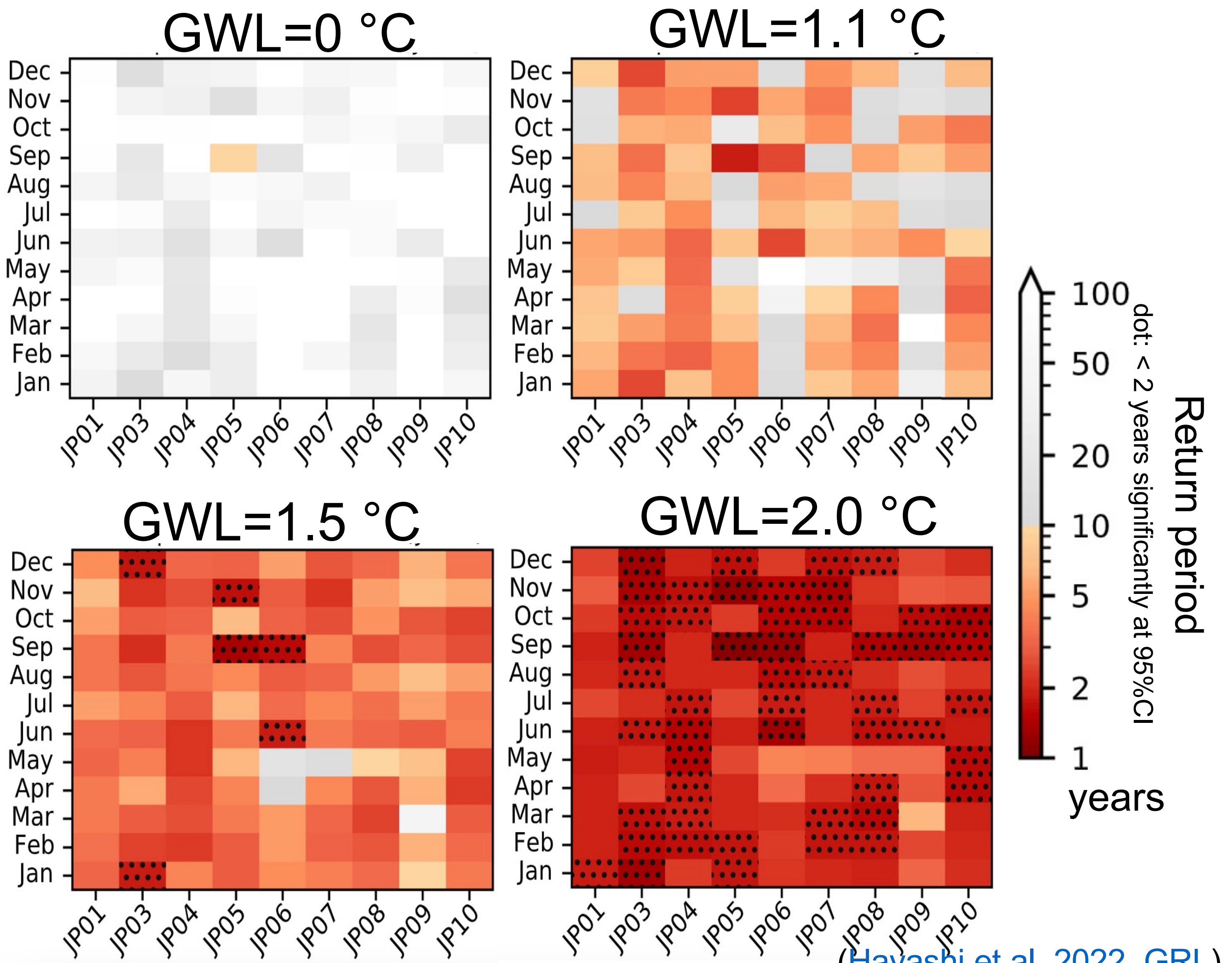


When “unprecedented high SST” becomes usual?

Return periods for the past highest SSTs are estimated in each Global Warming Level (GWL)

- GWL=0°C
  - Return period is >> 10-100 years
- GWL=1.1°C (~present)
  - Return period is ~ 10 years
- GWL=1.5°C
  - Return period is rarely < 2 years
- GWL=2.0°C
  - Return period is mostly < 2 years (=“unprecedented” → usual)

→Limiting GWL below 1.5°C is critical to avoid “(present) unprecedentedly high” becoming a new normal SST



(Hayashi et al. 2022, GRL)

Summary

We examined the contribution of climate change to monthly Extreme Ocean Warming (EOW) events near Japan for Jan 1982–Dec 2022

- EOW events are identified around Japan and FAR is estimated
  - Under the present climate, most of the identified EOW events are already attributable to climate change
  - All EOW events identified in 2022 are attributed to climate change
- Limiting GWL below 1.5°C is critical to avoid "past highest SSTs" becoming new normal conditions around Japan
- Physical drivers for each EOW event need to be further examined, by considering climate change and internal variability

(Hayashi et al. 2022, GRL) Monthly updated results are available on my website

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Any Questions?

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