Detecting anthropogenic effects on the record-warm northwestern Pacific sea surface temperature in August 2020

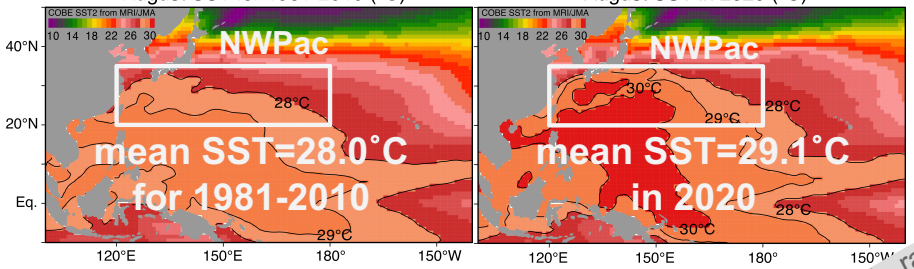
Michiya Hayashi*, Hideo Shiogama, Seita Emori, Tomoo Ogura, & Nagio Hirota @ National Institute for Environmental Studies (NIES), Japan.

EGU21-6925 @vEGU21 CL3.1.8 (2021-04-28 15:*36*-15:38 CEST) https://doi.org/10.5194/egusphere-egu21-6925

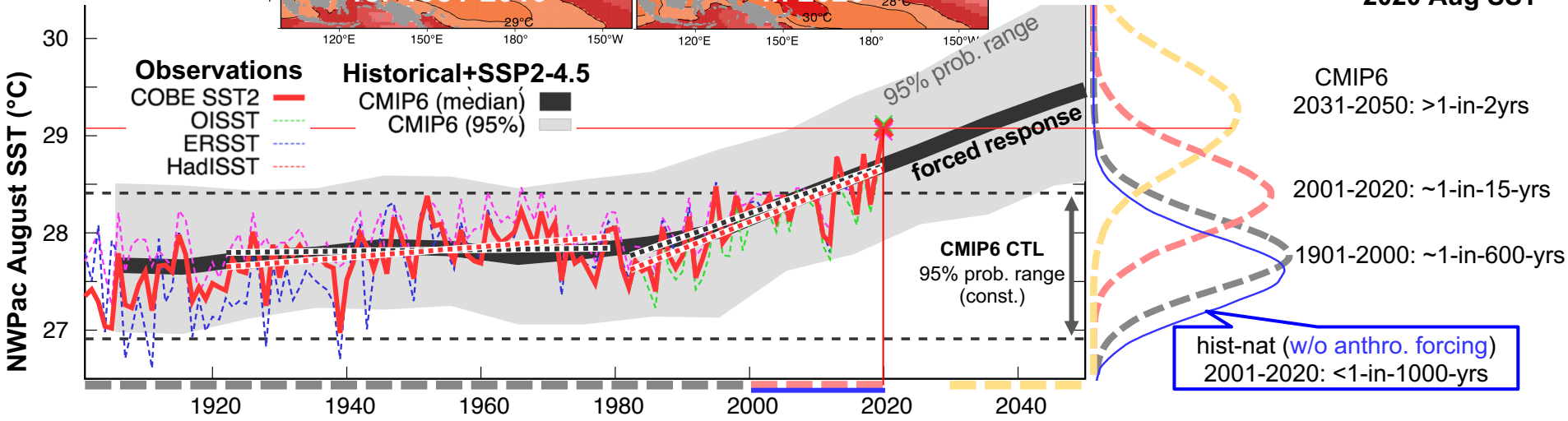
National Institute for Environmental Studies, Japan

- ✓ 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 changed the occurrence frequency of the record-high SST from <1-in-1000yr to 1-in-15yr

Observed August SST (°C)



Visit Our Published Article:
Hayashi et al. (2021, *GRL* Vol.48 issue.1)



Acknowledgements: This study was supported by the Integrated Research Program for Advancing Climate Models (JPMXD0717935457) (MEXT, Japan), JPMEERF20192004 (Environmental Restoration and Conservation Agency, Japan), and the Climate Change Adaptation Research Program of NIES.

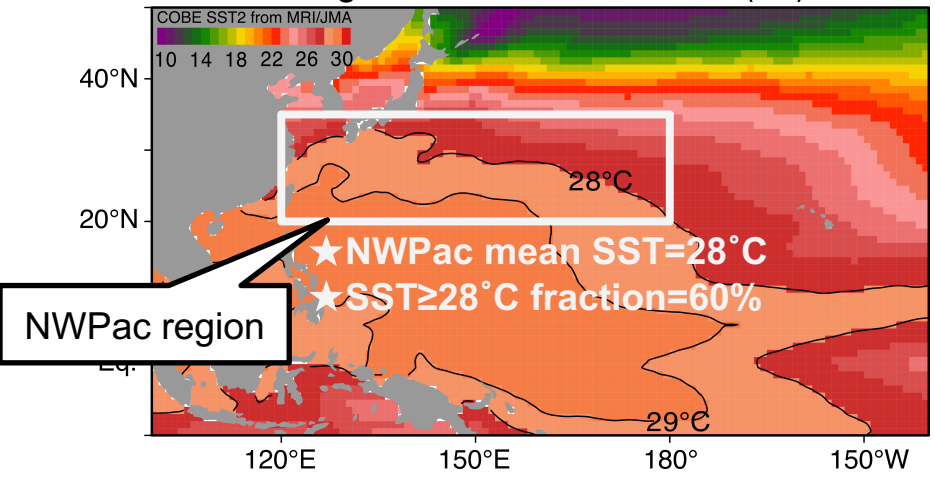
EGU21-6925 @vEGU21 CL3.1.8. https://meetingorganizer.copernicus.org/EGU21/session/40670 (2021-04-28 15:36-15:38 CEST / 22:36-22:38 JST)

Detecting anthropogenic effects on the record-warm northwestern Pacific sea surface temperature in August 2020

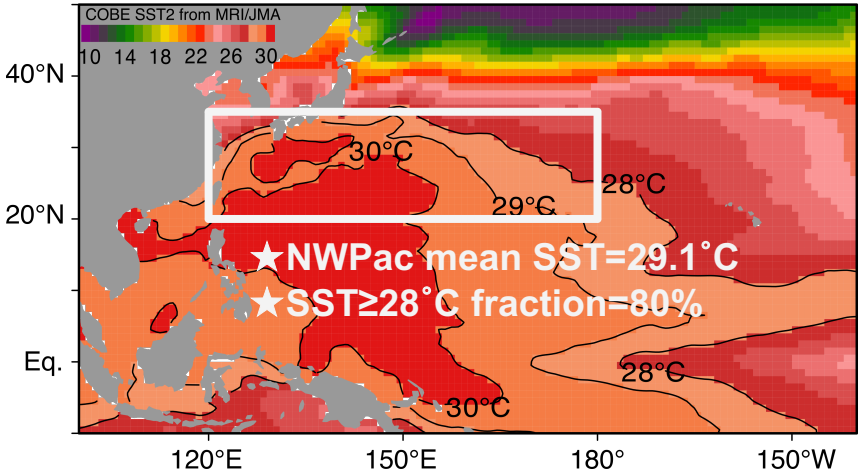
Michiya Hayashi*,
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National Institute for Environmental Studies (NIES)

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August SST for 1981-2010 (°C)

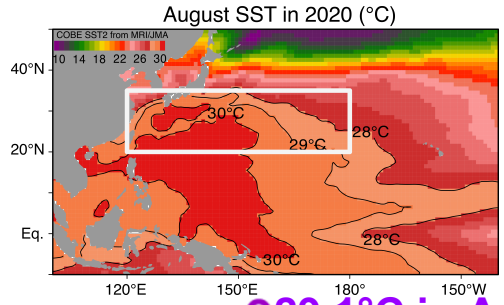


August SST in 2020 (°C)

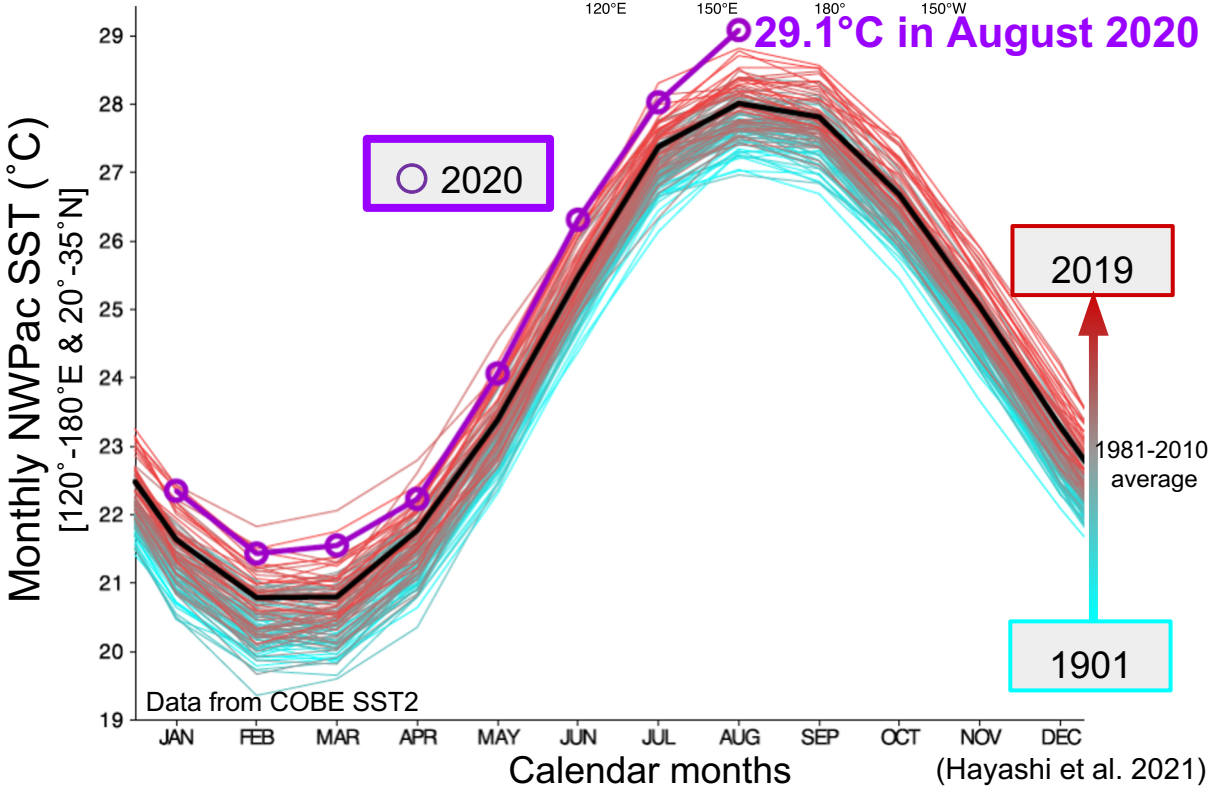


Article: Hayashi et al. The northwestern Pacific warming record in August 2020 occurred under anthropogenic forcing. *Geophys Res Lett* **48(1)** (2021).
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August 2020 set the record-high SST in the northwestern Pacific Ocean



- The warm SSTs ≥ 28°C seasonally expand to the south of Japan in August
- In August 2020, the NW Pacific SST was the highest since the 20th c.
  (NOAA 2020; JMA 2020)
  - Potentially strengthening typhoons (Emanuel 2005)
  - Affecting the ecosystem and human society



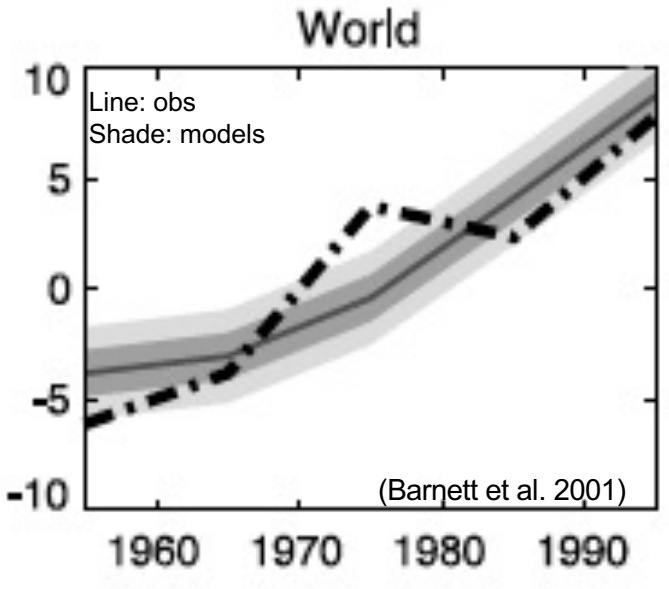
(Hayashi et al. 2021)

Human-caused changes in the world's oceans

- The global ocean heat content (OHC) has increased since the mid-20 c. (e.g., Levitus et al. 2000; Ishii & Kimoto 2009)
  - Since 1970, the upper 700-m OHC increased in the NW Pacific, Atlantic, and Southern Oceans (Palmer et al. 2017)
  - The Indo-Pacific warm pool tends to expand (Roxy et al. 2019)
- The warming is consistent with responses to natural + anthropogenic radiative forcings (e.g., Weller et al. 2016)

→ Could the record-high SST in the northwestern Pacific observed in August 2020 occur without anthropogenic forcing? (Hayashi et al. 2021)

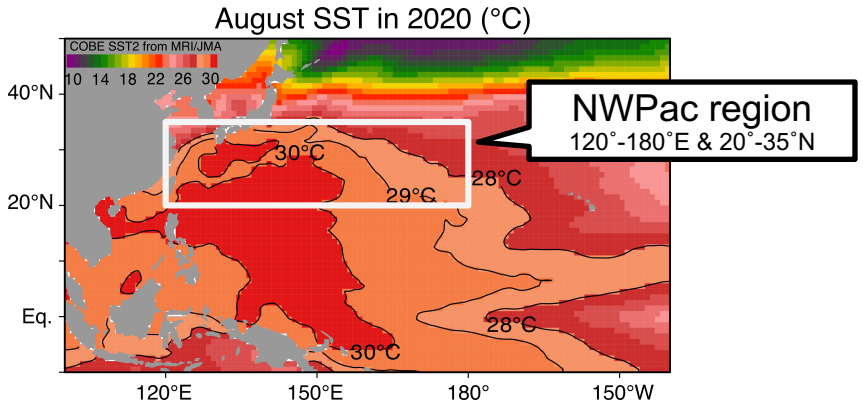
Decadal anomalies of upper 3000 m OHC (10^{22} J)



What we did in this study?

Detect the contribution of anthropogenic forcing to the NW Pacific SST in August 2020
Quantify long-term changes & future projections of NW Pacific warming

- **Observational datasets (monthly)**
  - Global SST in August: COBE SST2 (1850-2020)
    - Compared with ERSSTv5, OISSTv2.1, HadISSTv1.1
  - Global Ocean Temperature: ProjD v7.3.1 (1955-2020)
    - Compared with JCOPE2M (1993-2020)
- **Climate model outputs (monthly)**
  - CMIP6 (31 models x 1 member)
    - historical (1850-2014), SSP2-4.5 (2015-2100)
    - piControl (CTL for 200 years)
  - DAMIP (6 models x 3 members, 1850-2020)
    - hist-all (historical+SSP2-4.5)
    - hist-GHG (anthropogenic greenhouse-gas forcing only)
    - hist-aer (anthropogenic aerosol forcing only)
    - hist-nat (external natural forcing only)
- **Bias correction of mean-state SST in August**
  - The difference of mean SST for 1921-1980 between "historical" and COBE SST2 is removed at each grid point (Krinner et al. 2008)



- **Forced response & 95% probability range**
  - Ensemble median & 2.5th-97.5th percentiles
    - Every 10 years (1901-1910, 1911-1920, ...)
    - Constant for CTL (200 years)
  - 95% prob. range approximately related to internal variability until 2020 (→CMIP6 large ensembles)

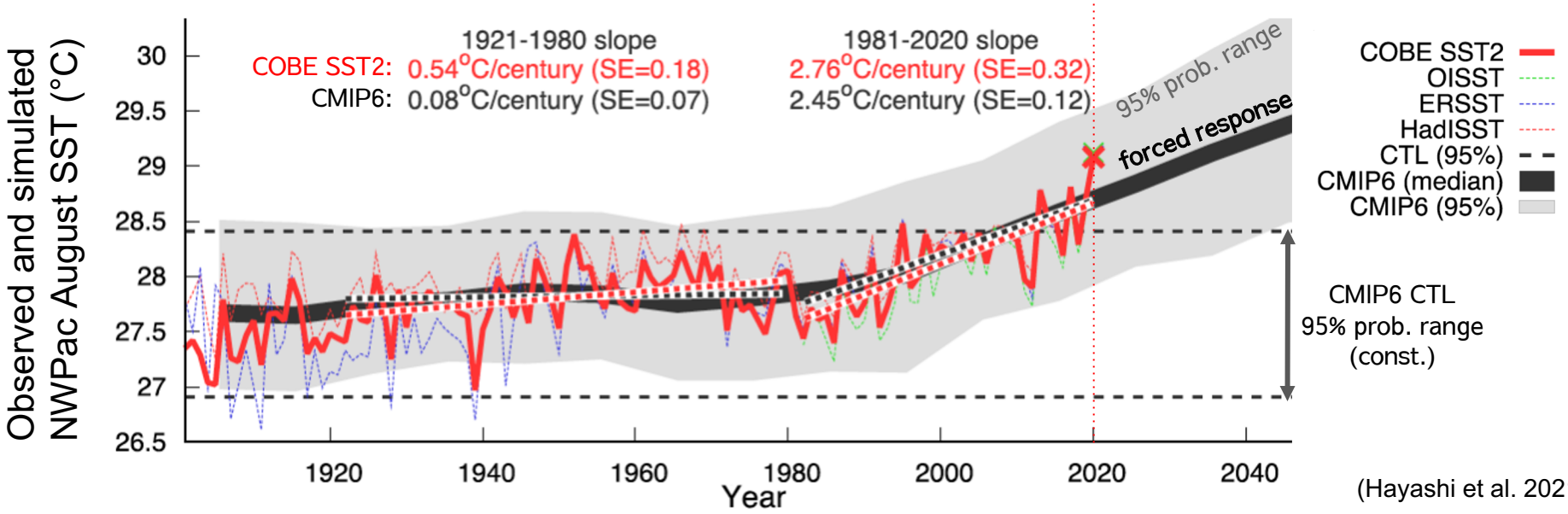
Table S1.
CMIP6 experimental ID and ECS

Model name	CMIP6 (historical, SSP2-4.5, CTL)	DAMIP (hist-all, hist-GHG, hist-aer, hist-nat)	Large ensembles (historical, SSP5-8.5)	ECS (K)
ACCESS-CM2	r1i1p1f1			4.7
ACCESS-ESM1-5	r1i1p1f1			3.9
BCC-CSM2-MR	r1i1p1f1			3.0
CESM2-WACCM	r1i1p1f1			4.8
CESM2	r1i1p1f1			5.2
CNRM-CM6-1-HR	r1i1p1f2			4.4
CNRM-CM6-1	r1i1p1f2			4.9
CNRM-ESM2-1	r1i1p1f2			4.7
CanESM5-CanOE	r1i1p2f1			5.6
CanESM5	r1i1p2f1	r1i1p2f1-r3i1p2f1	r1i1p2f1-r25i1p2f1	5.6
EC-Earth3-Veg	r1i1p1f1			4.3
EC-Earth3	r1i1p1f1			4.1
FGOALS-f3-L	r1i1p1f1			3.0
FGOALS-g3	r1i1p1f1	r1i1p1f1-r3i1p1f1		2.9
FIO-ESM-2-0	r1i1p1f1			4.2
GFDL-CM4	r1i1p1f1			3.9
GFDL-ESM4	r1i1p1f1			2.7
GISS-E2-1-G	r1i1p1f2			2.7
HadGEM3-GC31-LL	r1i1p1f3*	r1i1p1f3-r3i1p1f3		5.6
INM-CM4-8	r1i1p1f1			1.8
INM-CM5-0	r1i1p1f1			1.9
IPSL-CM6A-LR	r1i1p1f1	r1i1p1f1-r3i1p1f1		4.5
MIROC-ES2L	r1i1p1f2			2.7
MIROC6	r1i1p1f1	r1i1p1f1-r3i1p1f1	r1i1p1f1-r50i1p1f1	2.6
MPI-ESM1-2-HR	r1i1p1f1			3.0
MPI-ESM1-2-LR	r1i1p1f1			3.0
MRI-ESM2-0	r1i1p1f1	r1i1p1f1-r3i1p1f1		3.2
NESM3	r1i1p1f1			4.7
NorESM2-LM	r1i1p1f1			2.6
NorESM2-MM	r1i1p1f1			2.5
UKESM1-0-LL	r1i1p1f2			5.4

Note. ECS was computed using the Gregory method (Gregory et al., 2004) except for that of CanESM5-CanOE, which was not available at the CMIP6 data archive and retrieved from Table 2 of McKitrick and Christy (2020). Red numbers indicate the ECS higher than 4.5 K. *Experiment r1i1p1f1 was available for CTL of HadGEM3-GC31-LL in the data archive.

Climate models well reproduce the long-term changes in the NWPac SST

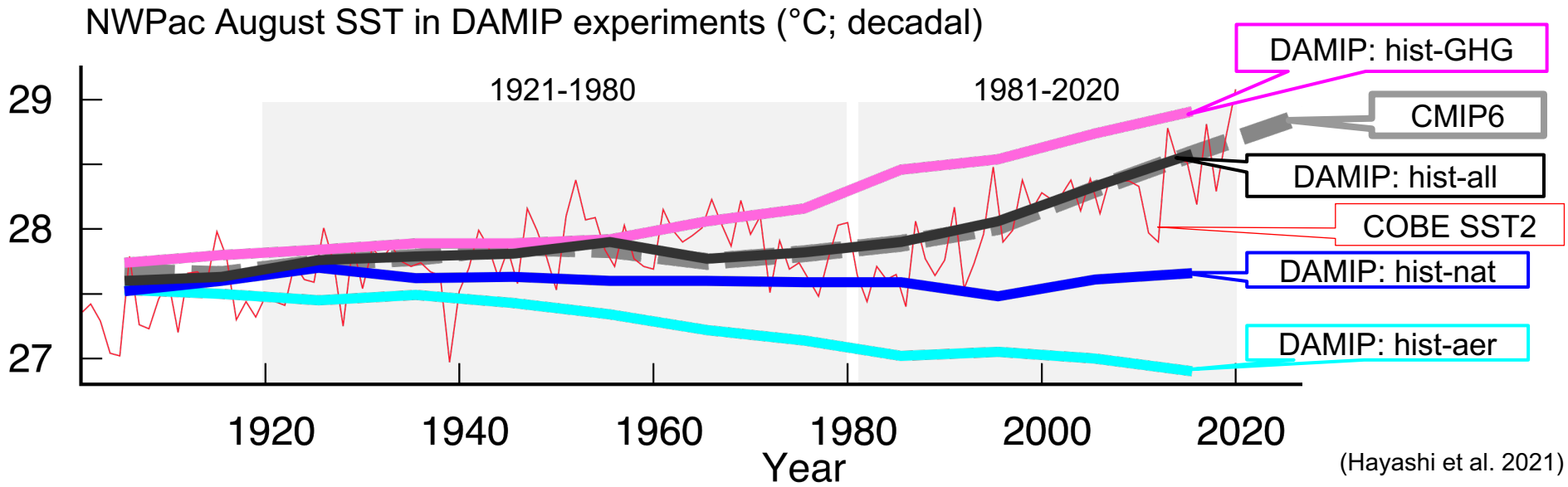
- The observed SST is covered by CMIP6 with the 95% range & forced response
  - The linear trend is negligible for 1921-1980 but significantly positive for 1981-2020
  - The forced response exceeds the 95% prob. range of CTL since the 2010s
- The 2020 event (**x**) is
  - almost impossible to occur in the preindustrial era
  - within the 95% prob. range (> once per 20 years) if the warming since 1980s is considered



(Hayashi et al. 2021)

Contribution of anthropogenic forcings to NWPac SST

- The forced response in CMIP6 (31 models) is reproduced by the hist-all (6 models)
- In 1921-1980, the GHG-caused warming is canceled by the aerosol-caused cooling
- In 1981-2020, the GHG-caused warming is dominant



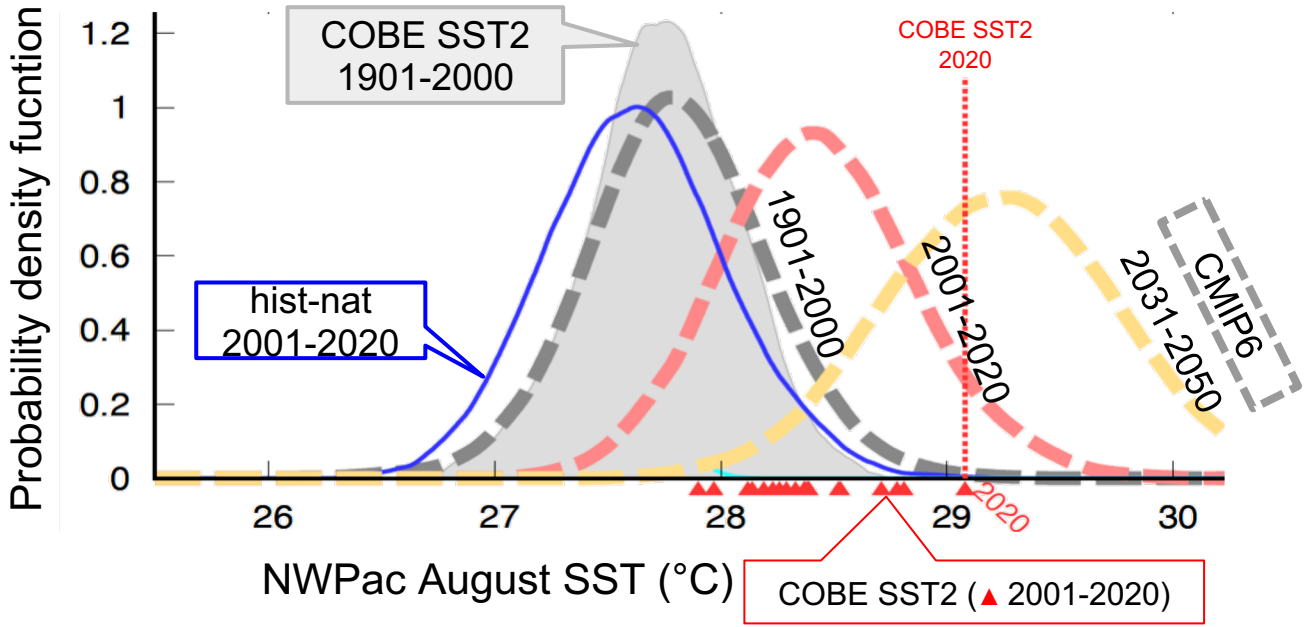
(Hayashi et al. 2021)

1-in-1000-year event became 1-in-15-year event due to anthropogenic forcing

- Estimated occurrence frequency of the 2020 August event
  - 1901-2000 w/ anthropogenic forcing (CMIP6): ~1-in-600-years (0.16 [0.07-0.26]%/year)
  - 2001-2020 w/ anthropogenic forcing (CMIP6): ~1-in-15-years (6.9 [5.5-8.5]%/year)
  - 2001-2020 w/o anthropogenic forcing (hist-nat): <1-in-1000-years (0.03 [0.00-0.10]%/year)

➔ The 2020 event likely occurred due to the anthropogenic forcing

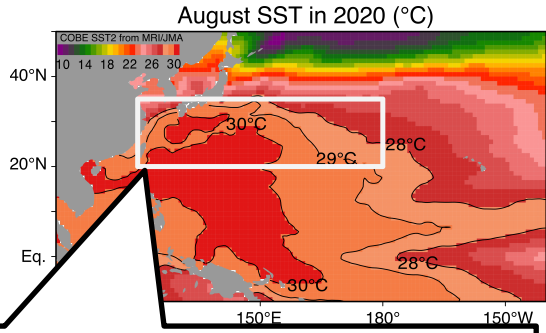
- The high SST in August 2020 is becoming the new normal climate by 2031-2050



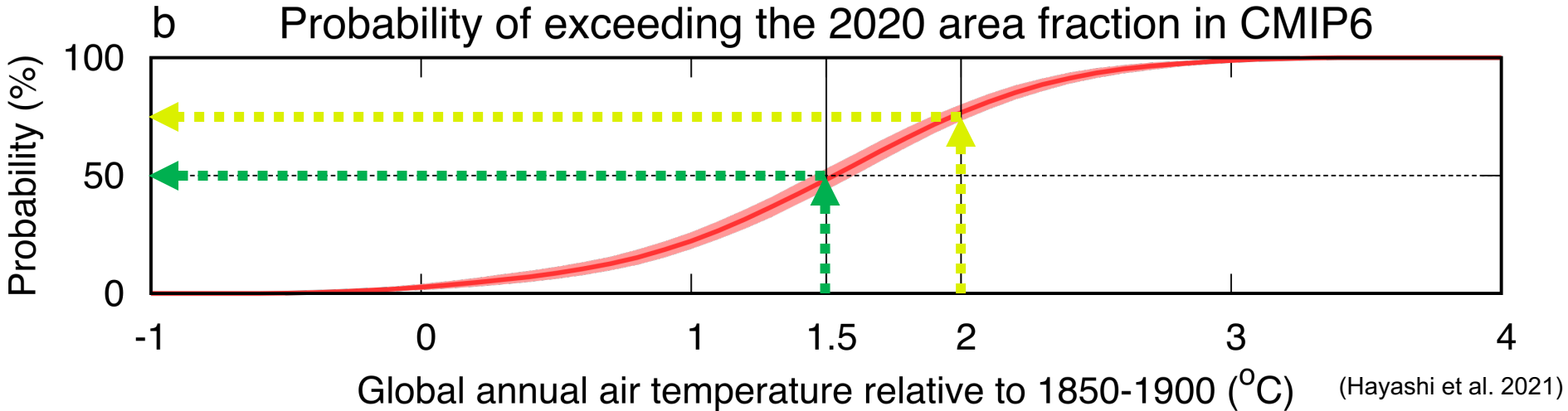
(Hayashi et al. 2021)

NWPac warm-pool expansion vs Global warming level

- Area fraction≥28°C in NWPac increases w.r.t. global warming
- Once **global warming reaches ≥1.5°C** (by ~2031-2040), the NWPac warm pool expansion observed in August 2020 is likely to be **the new normal climate** (50%= once in 2 years)



NWPac area fraction of SST≥28°C
= 80.0-84.4% in 2020

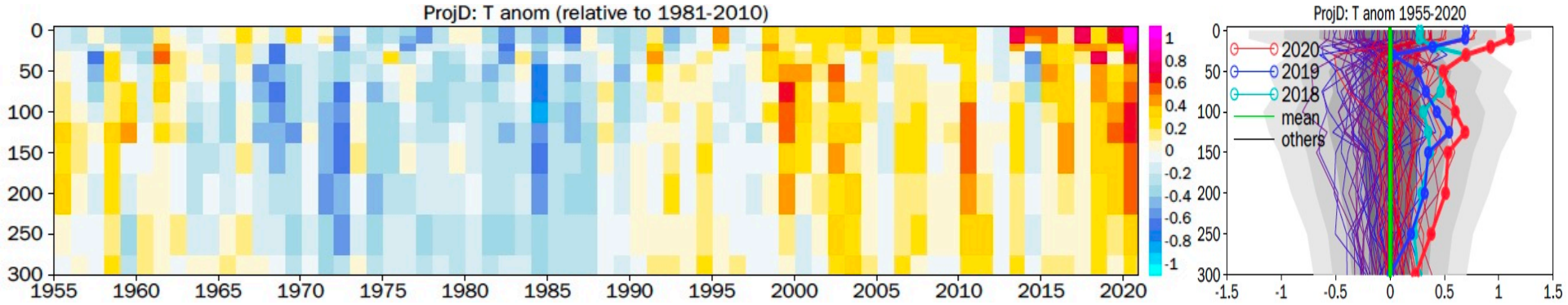


(Hayashi et al. 2021)

Discussion: Contributions of internal variability to the 2020 event?

- **Long-term trend** (anthropogenic warming)
- **Interannual/decadal variability** (oceanic and/or air-sea coupled internal phenomena?)
- **Short-term variability in August 2020** (atmospheric internal phenomena?)
  - Anti-cyclonic anomaly over the NWPac in August 2020, enhancing the shortwave heating? (JMA 2020)
  - No typhoon occurrence in July 2020, resulting in less upper ocean mixing?

➔ **Regardless of the related internal variability,**
the anthropogenic forcing made the 2020 event possible to happen in the present climate at ~ observed frequency

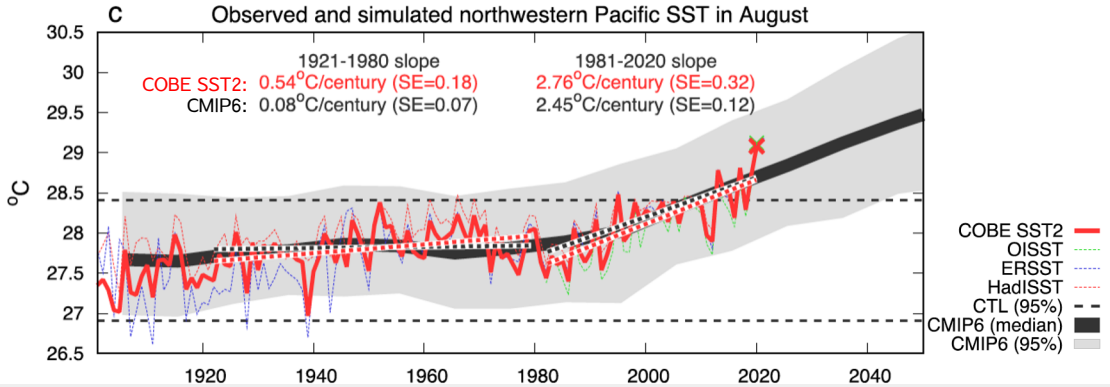


Data from Ishii et al. (ProjD v7.3.1: 1955-2020)

(Hayashi et al. 2021; updated)

Summary

- August 2020 set the record high SST in the northwestern Pacific since the 20th c.
- The 2020 event is within the 95% prob. range if warming since 1980 is considered
  - Since the 1980s, GHG-caused warming dominates aerosol-caused cooling
  - Multiple factors may have contributed to the 2020 event (calling to explore related internal variability)
- Anthropogenic forcing has altered the occurrence frequency of the 2020 event
  - Increased from <once per 1000 years to ~ once per 15 years for 2001-2020
- Once global warming exceeds 1.5°C (~2031-2040), the record-high level of the northwestern Pacific SST in August 2020 is likely to become a new normal climate



(Hayashi et al. 2021)

Article: Hayashi et al. The northwestern Pacific warming record in August 2020 occurred under anthropogenic forcing. *Geophys Res Lett* **48(1)** (2021).
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http://www.nies.go.jp/whatsnew/20210114-2/20210114-2-e.html

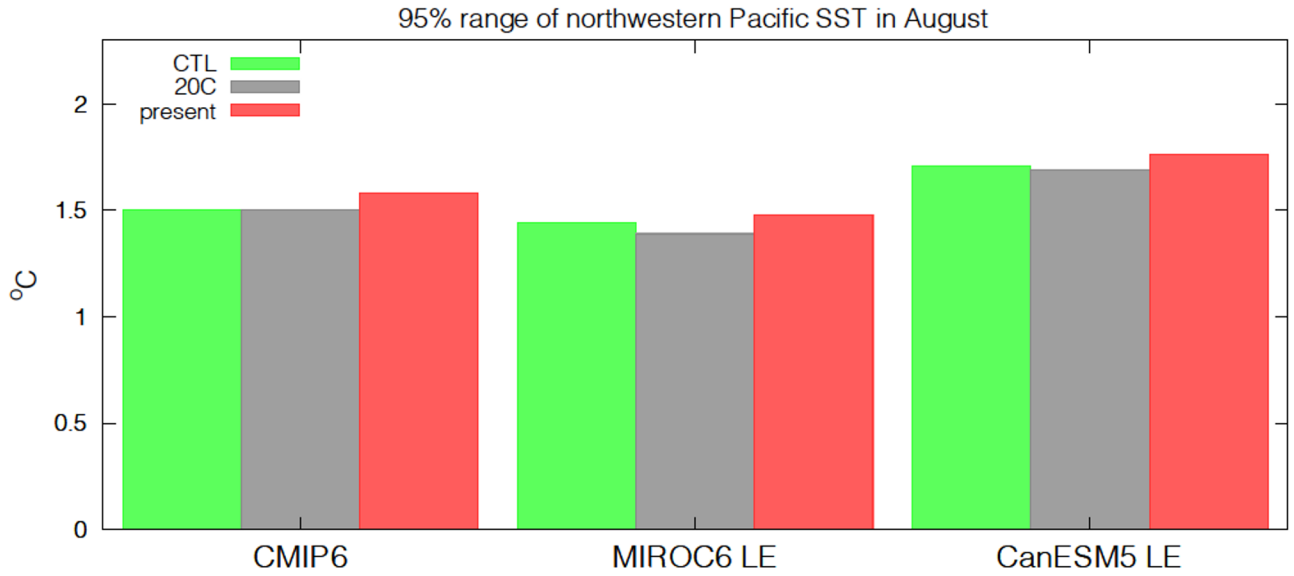
Massages from this study

- *We might need to prepare for living with such warm ocean conditions even if we humans could achieve the 1.5°C goal of the Paris Agreement*
- *It is time to take prompt actions to transform our society for reducing the greenhouse gas emissions and for adapting to a changing climate.*

Supplementary Materials

The uncertainty range almost unchanged from preindustrial to present

The internal variability is dominant until the present climate

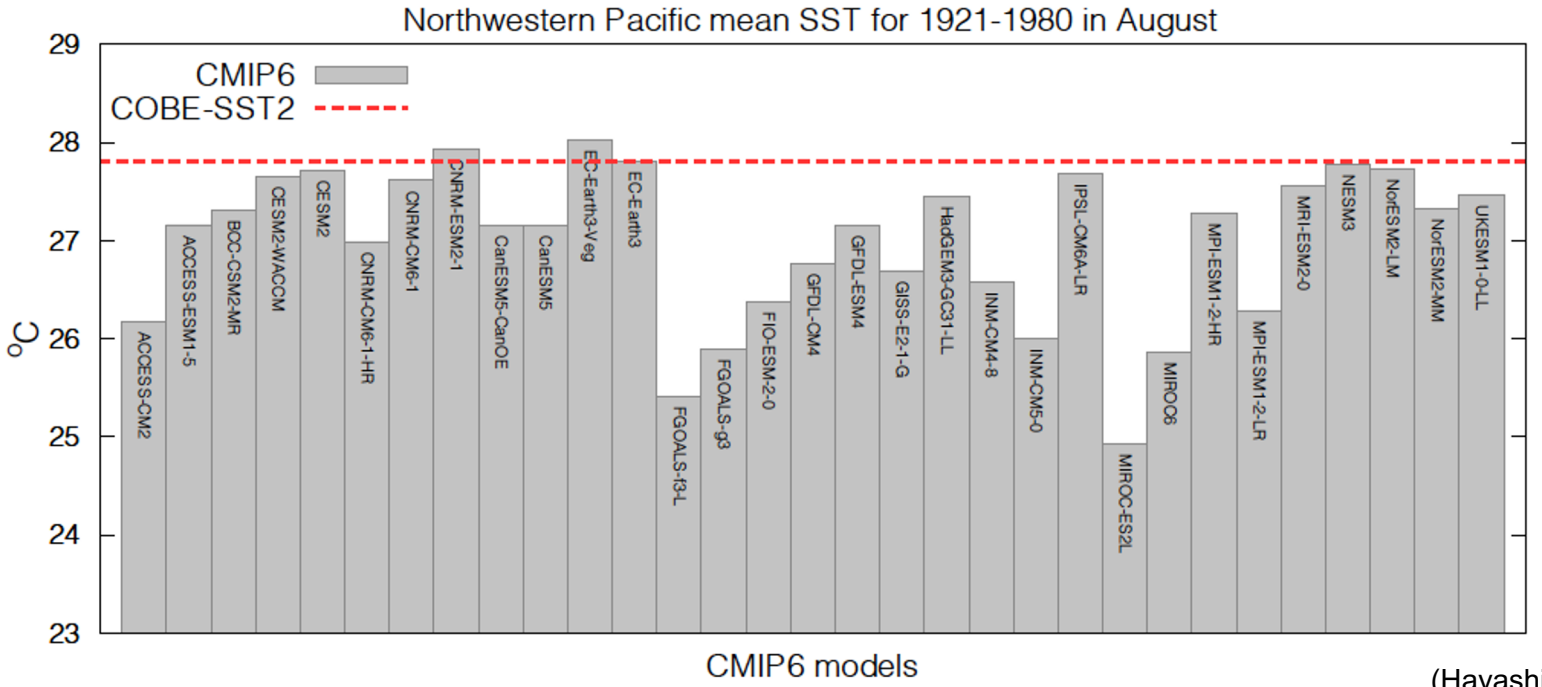


- CMIP6 large ensembles
  - MIROC6 50-member (Tatebe et al. 2019)
  - CanESM5 25-member (Swart et al. 2019)
  - Used only for evaluating the changes in the internal variability range for 1850-2020 (historical, SSP5-8.5)

(Hayashi et al. 2021)

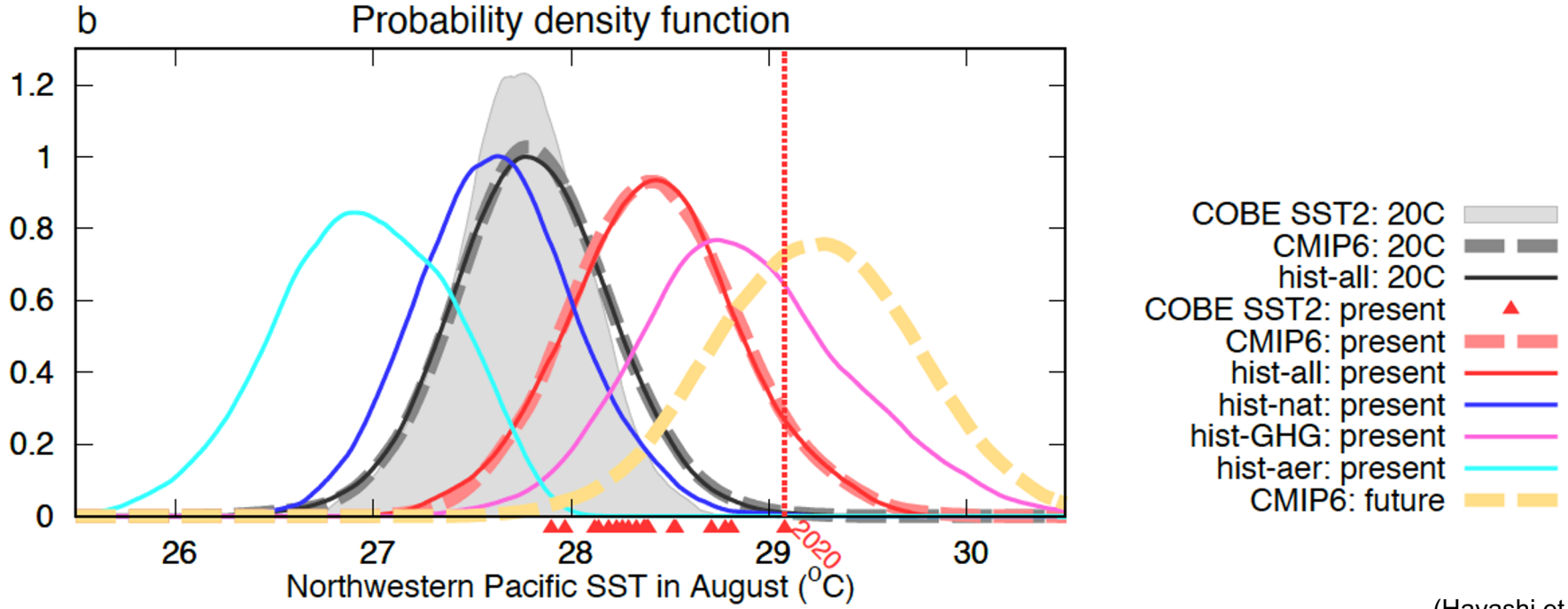
NWPac SST bias in August for 1921-1980

- Many models suffer from too cold mean SST in the northwestern Pacific
- This bias is corrected to focus on the forced response in SST
- The 1921-1980 period is used for bias correction as the long-term trend is negligible



(Hayashi et al. 2021)

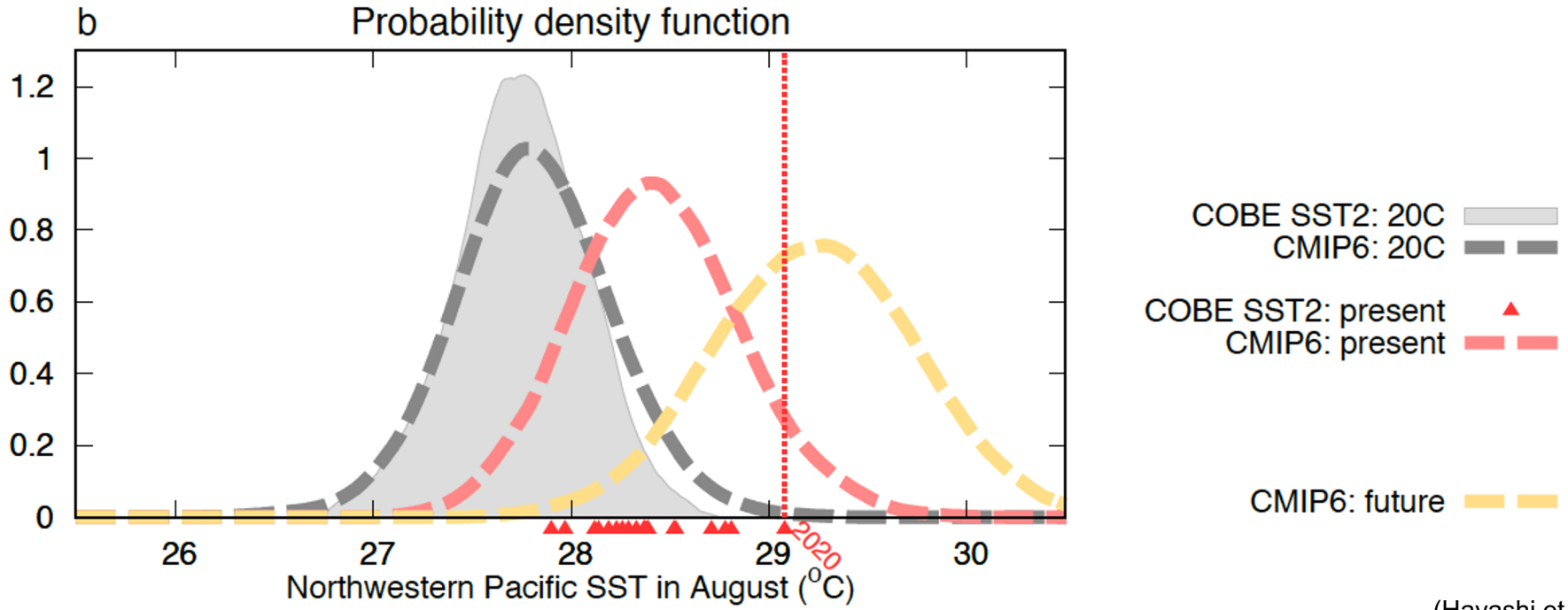
Occurrence frequency of the SST observed in August 2020



(Hayashi et al. 2021)

Occurrence frequency of the SST observed in August 2020

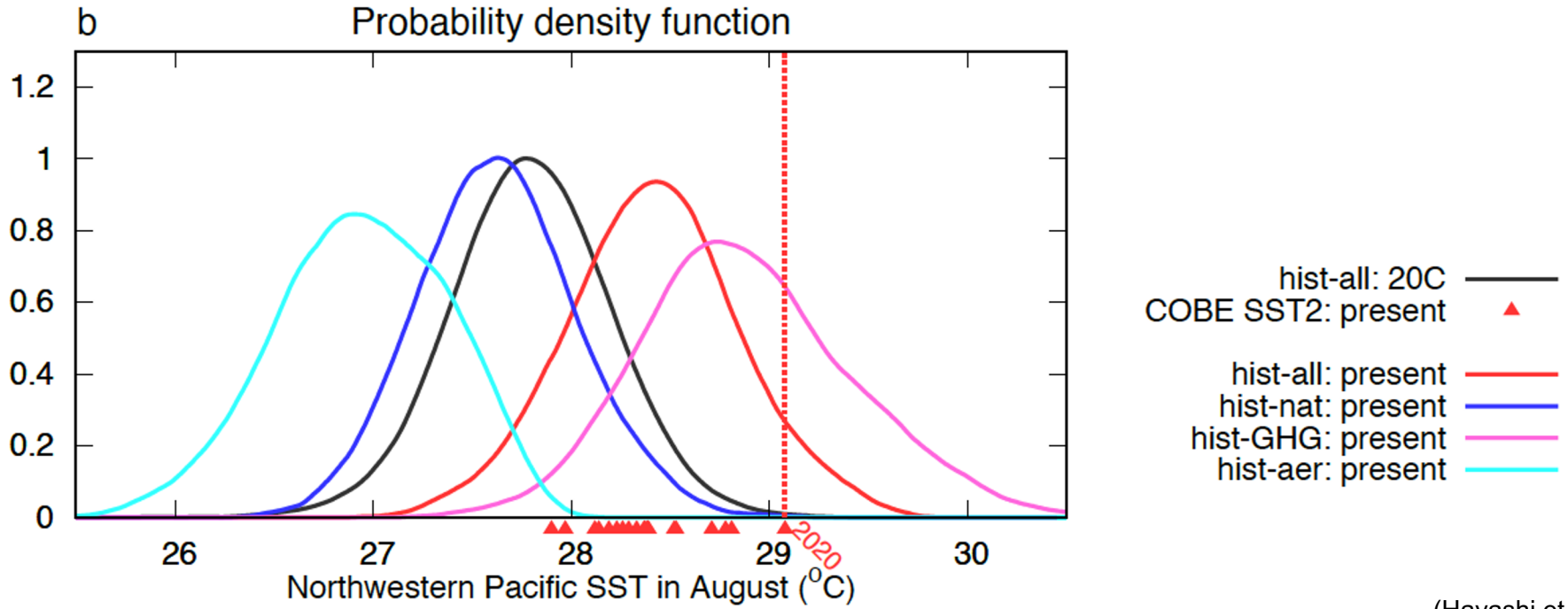
Observations and CMIP6 only



(Hayashi et al. 2021)

Occurrence frequency of the SST observed in August 2020

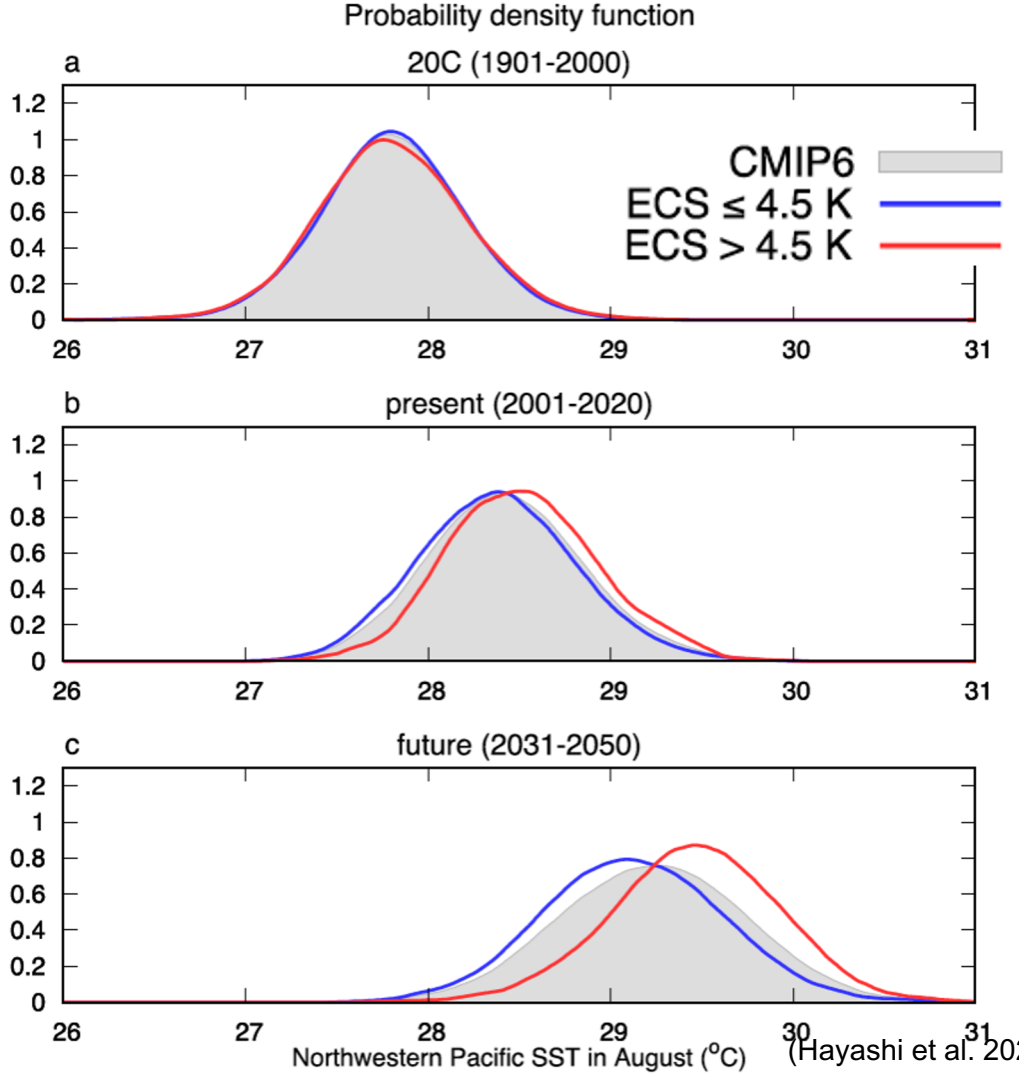
DAMIP only



(Hayashi et al. 2021)

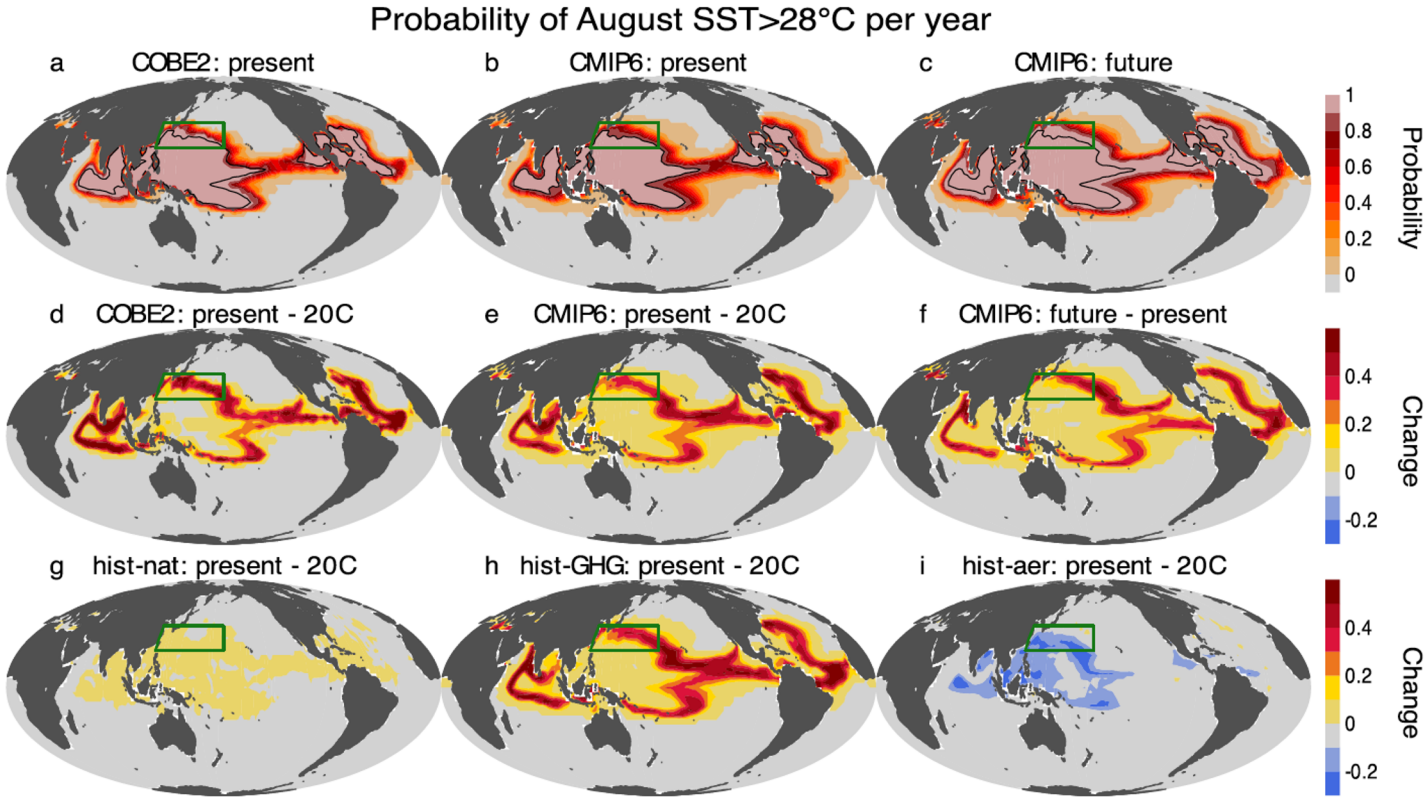
Dependence on ECS

- ECS>4.5 K may be unrealistic (Tokarska et al., 2020; Njisse et al., 2020; Liang et al., 2020)
- ECS>4.5 K models (10/31 models) overestimate the future projection
- But the major results in this study are less affected even if the ECS>4.5 K models were removed



(Hayashi et al. 2021)

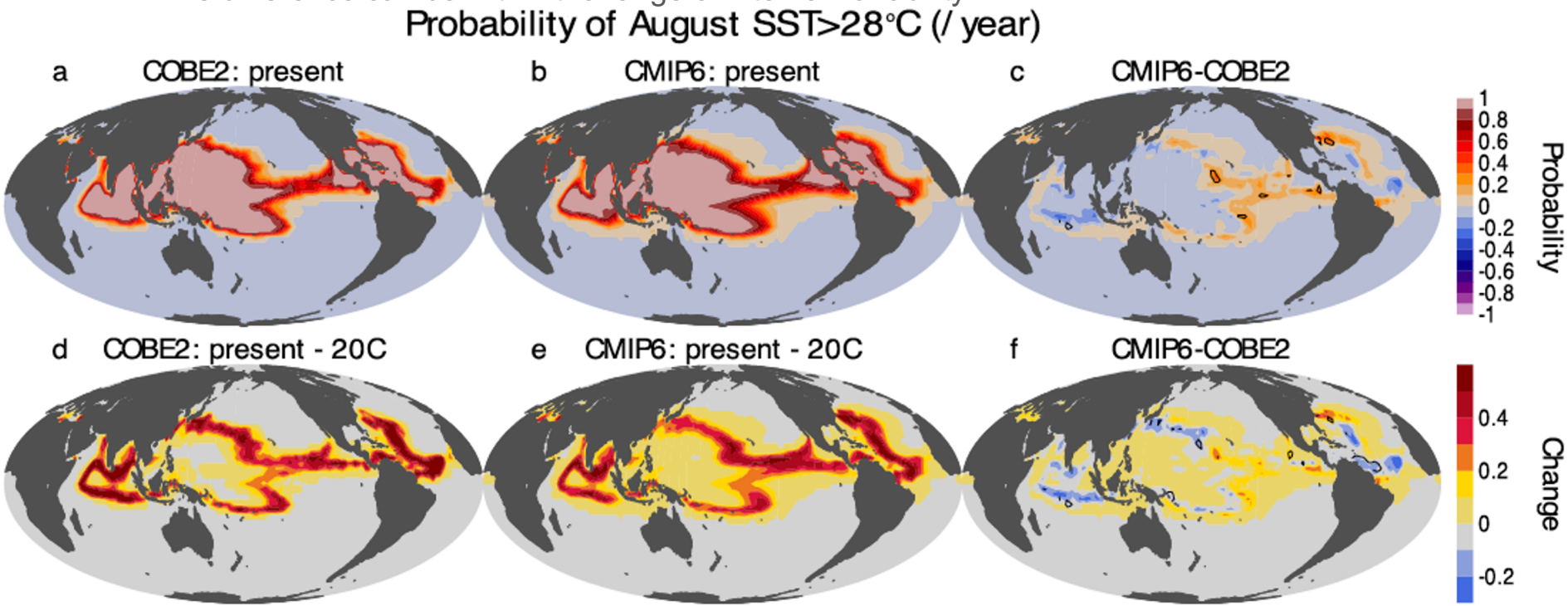
Global warm pool expansion due to global warming



(Hayashi et al. 2021)

Global warming expansion: CMIP6 vs observations

- Difference between CMIP6 MME & COBE SST2 is ~ less than 2 st.d. of CMIP6
  - The difference can be within the range of internal variability



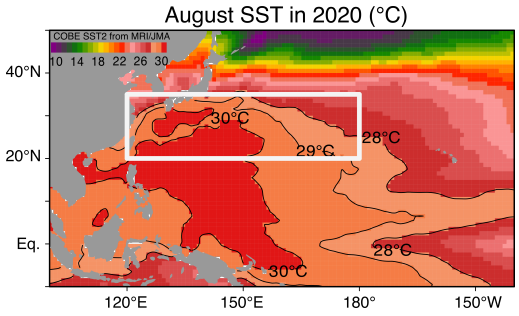
(c,f) The contours are rarely visible as a result.

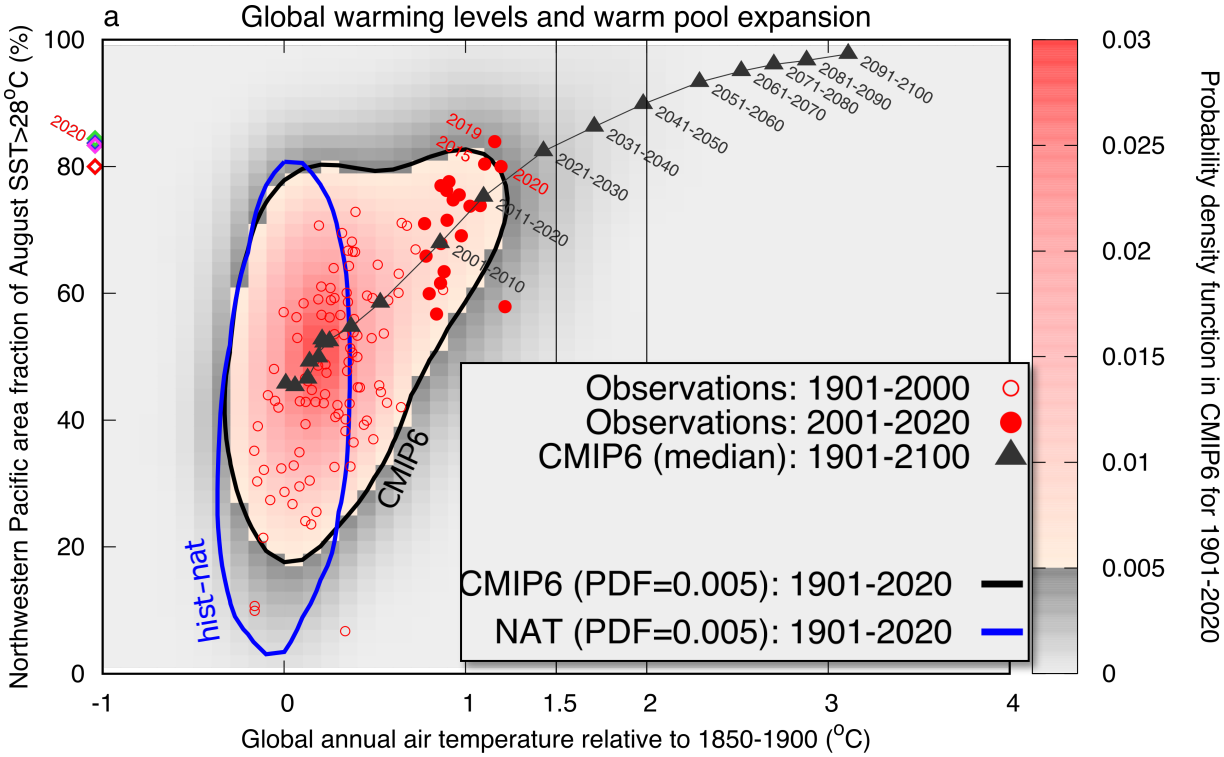
(Hayashi et al. 2021)

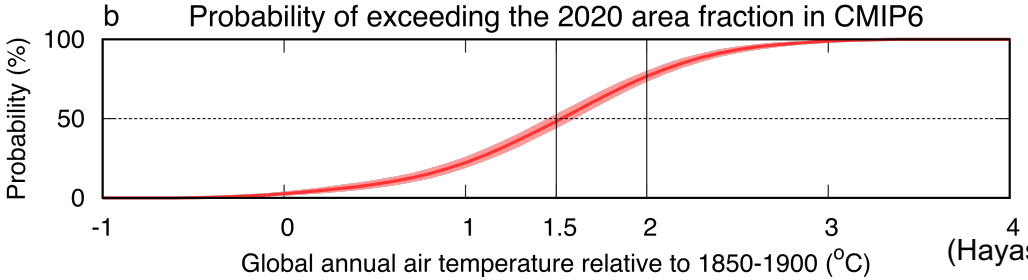
Global warming level v.s. warm-pool expansion

Global annual air temperature:
Cowtan & Way (1850-2020)

- Area fraction≥28°C in NWPac increases w.r.t. global warming
  - Consistent bw obs. and CMIP6
  - Since 2001, the fraction >50% (~median in hist-nat)
- Once global warming reaches ≥1.5°C (by ~2031-2040), the warm pool expansion observed in August 2020 is likely to be the new normal climate condition



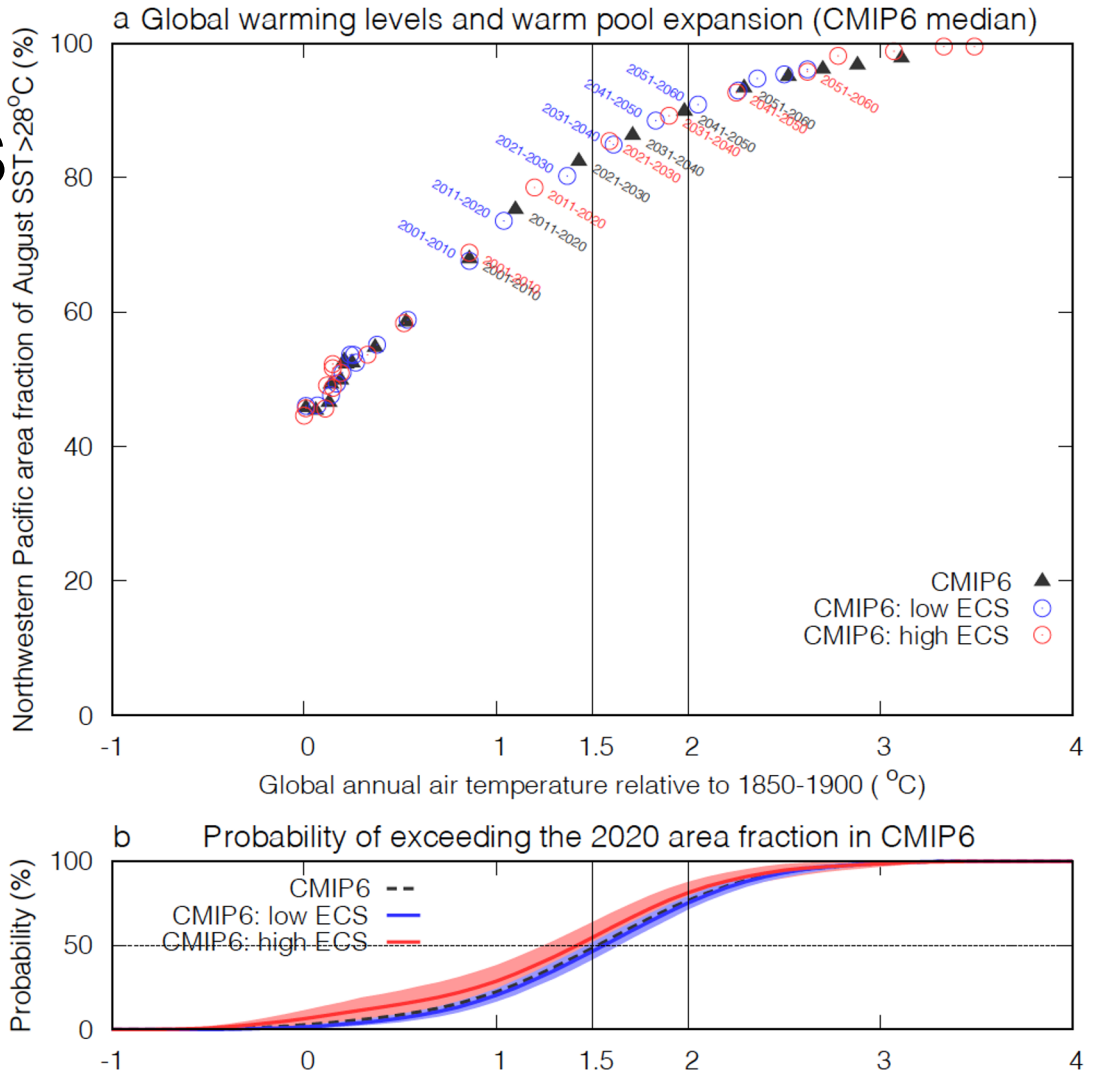




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