Changes and mechanisms of long-lived warm blobs in the Northeast Pacific in low-warming climates

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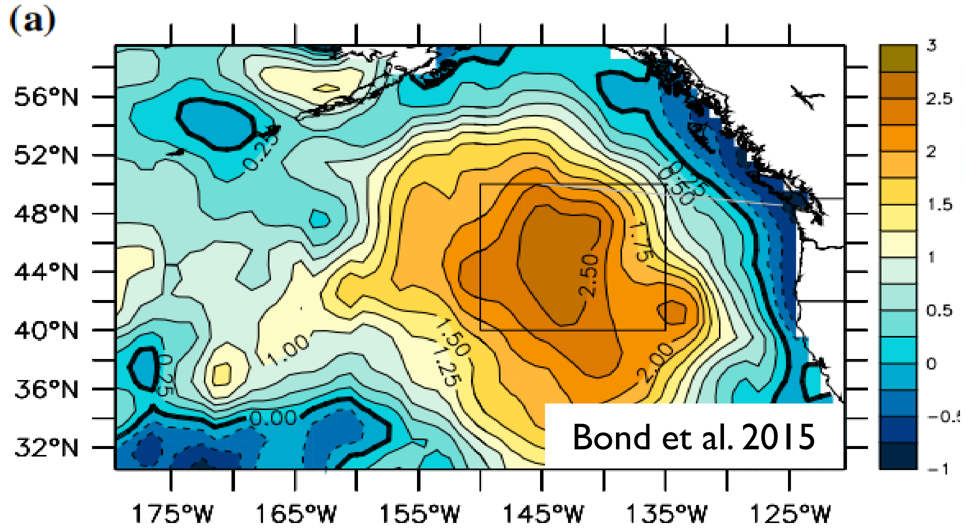
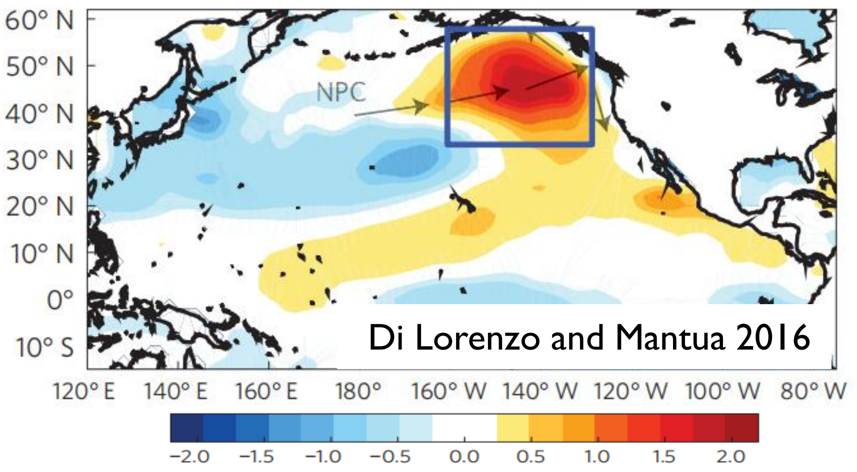
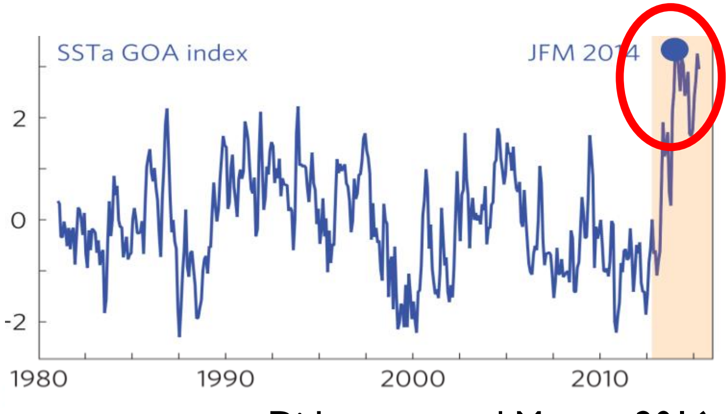
Motivation —— "The Blob"



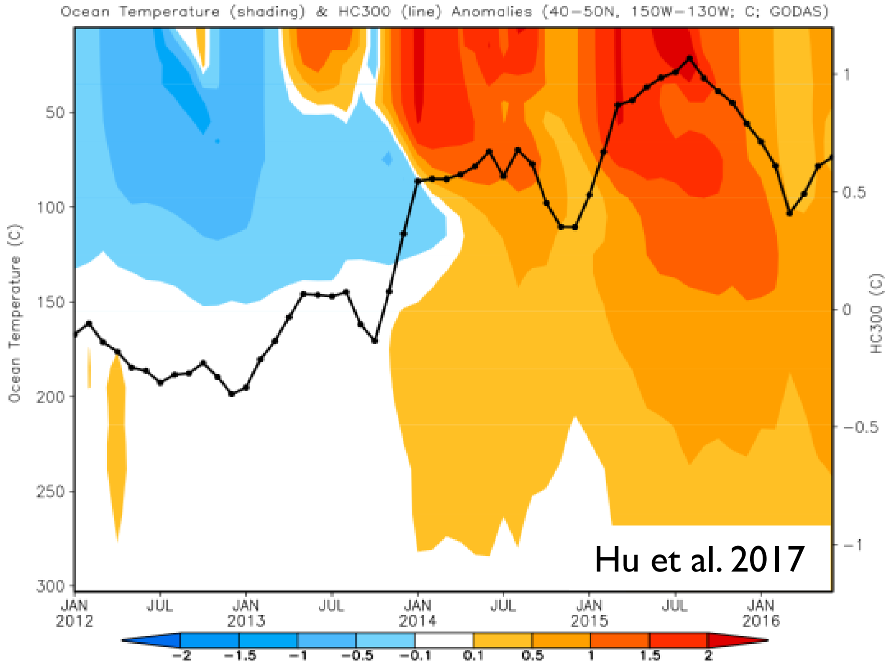
Bond et al. 2015



Di Lorenzo and Mantua 2016



Di Lorenzo and Mantua 2016

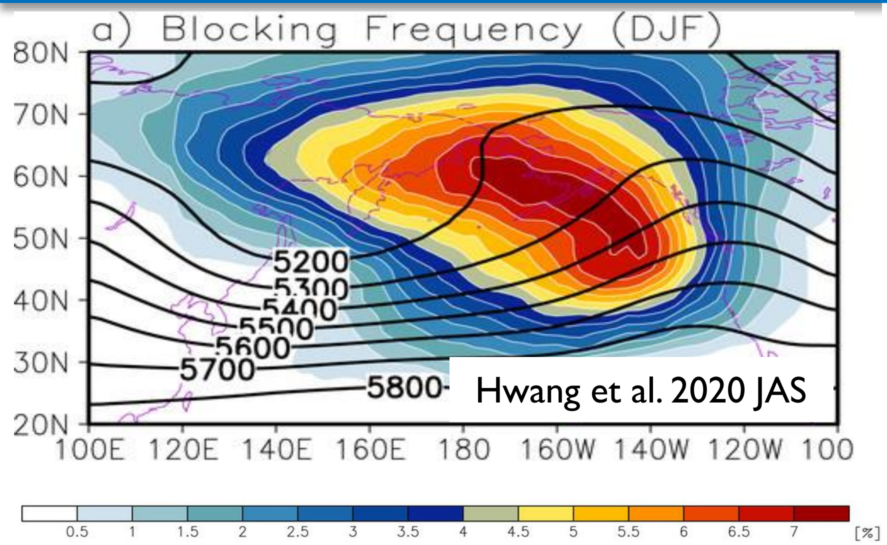


Hu et al. 2017

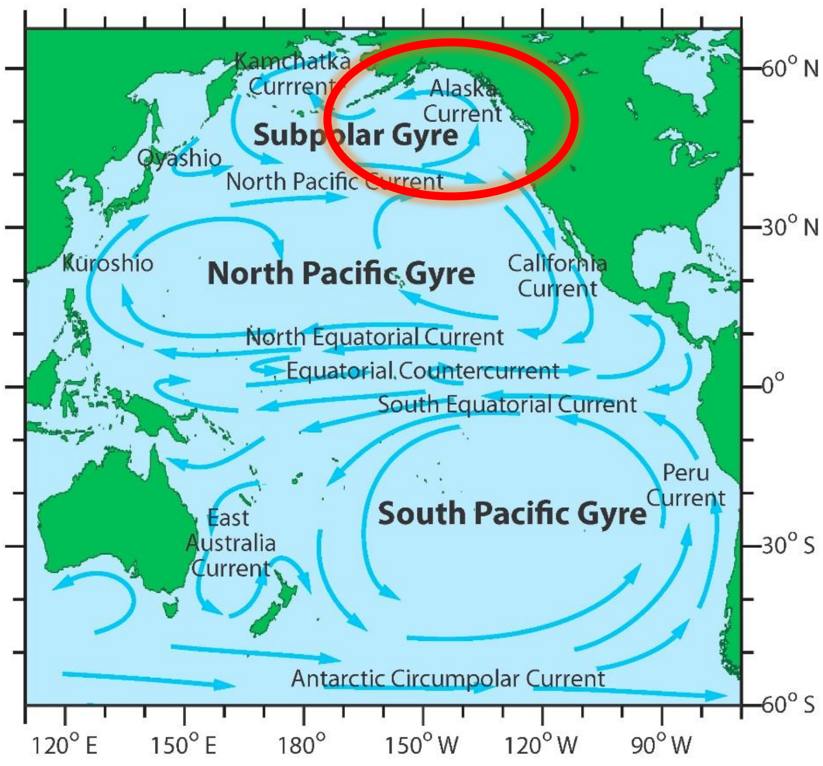
Characteristics of The Blob:

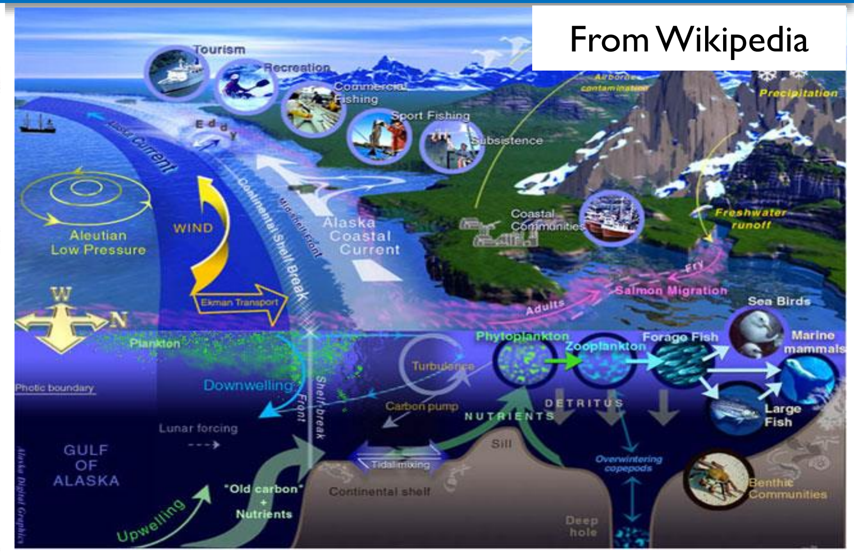
- Extend from the Northeast Pacific to the Gulf of Alaska (GOA)
- Monthly sea surface temperature (SST) anomaly can exceed 3 °C
- Multi-year persistence from late 2013 to early 2016
- Originated at the oceanic surface and propagated downward and reached about 300 m

Why are Northeast Pacific and GOA important?

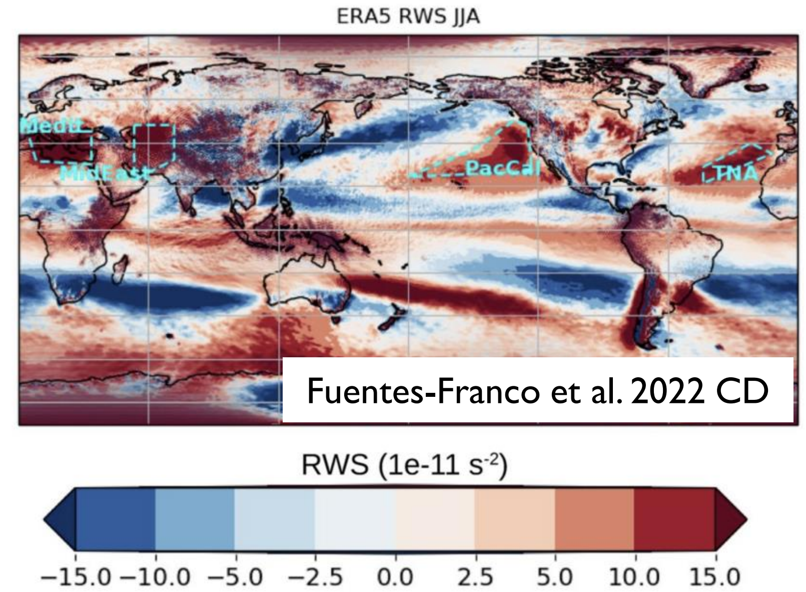


Hwang et al. 2020 JAS

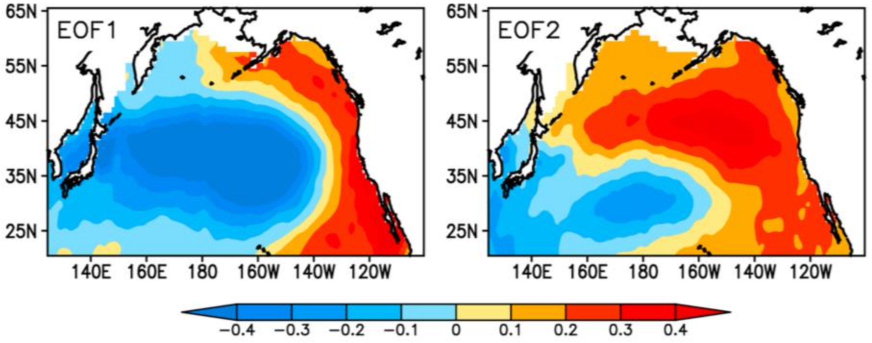




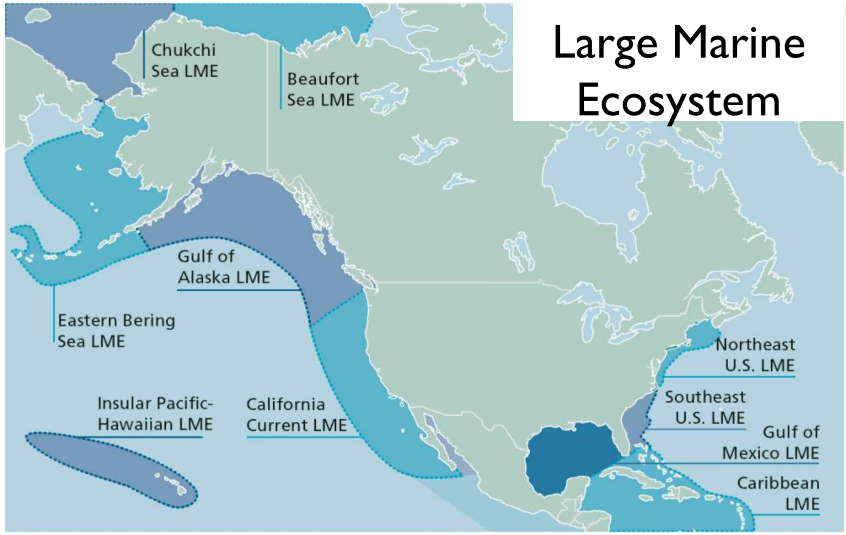
From Wikipedia



Fuentes-Franco et al. 2022 CD

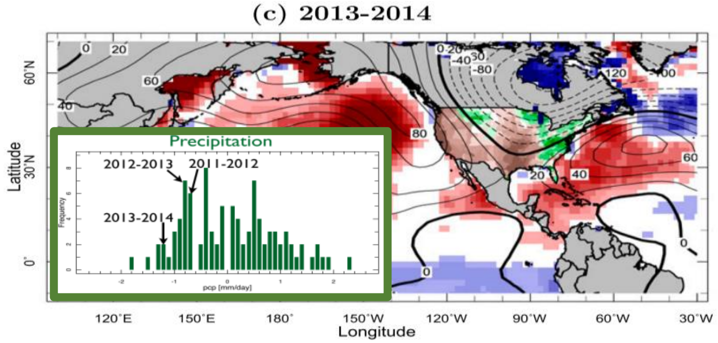


Ding et al. 2015, JGR

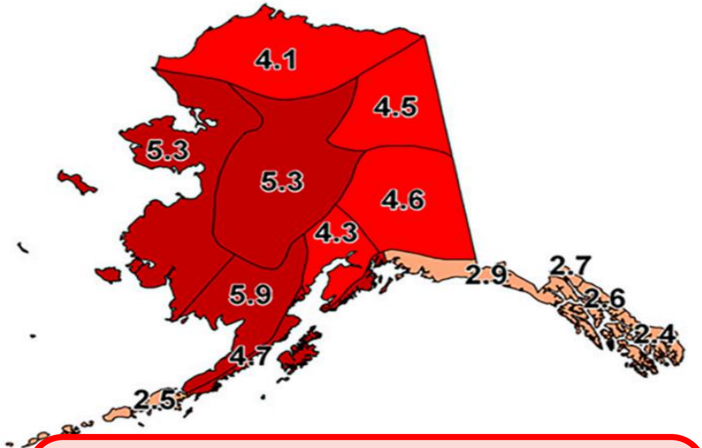


Large Marine Ecosystem

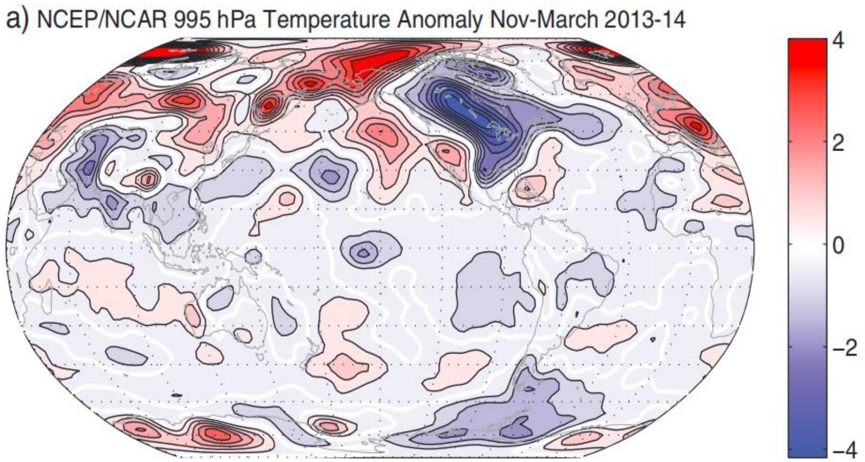
Climate effects of "The Blob"



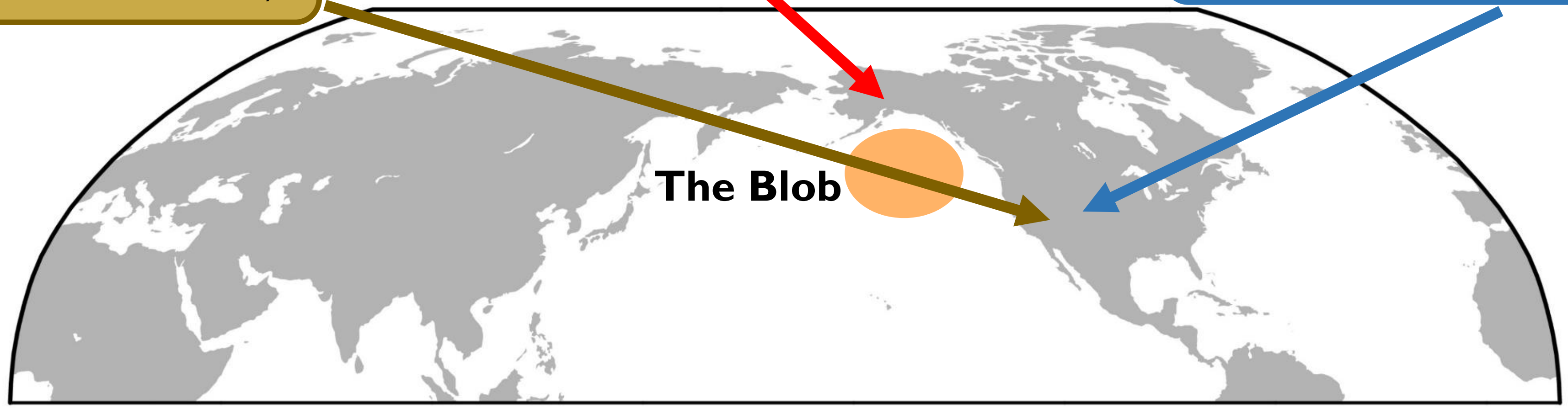
- Severe drought in California (Seager et al. 2015; Shi et al. 2021)



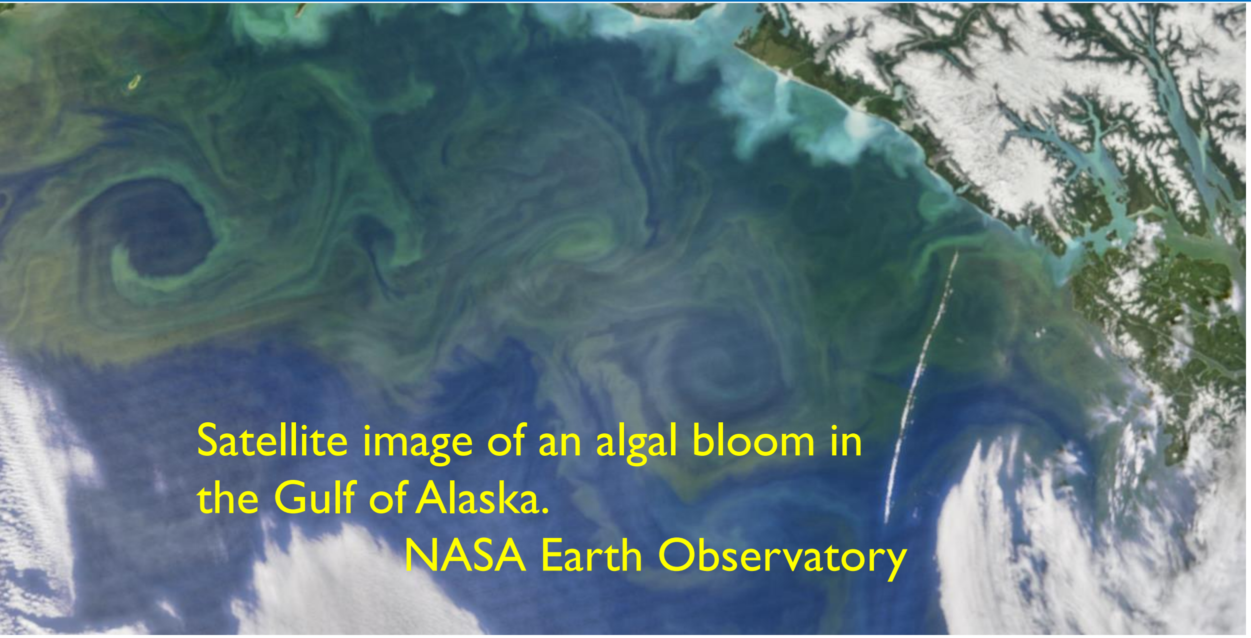
- Exceptionally warm winter of 2015/16 in Alaska (Walsh et al. 2017)

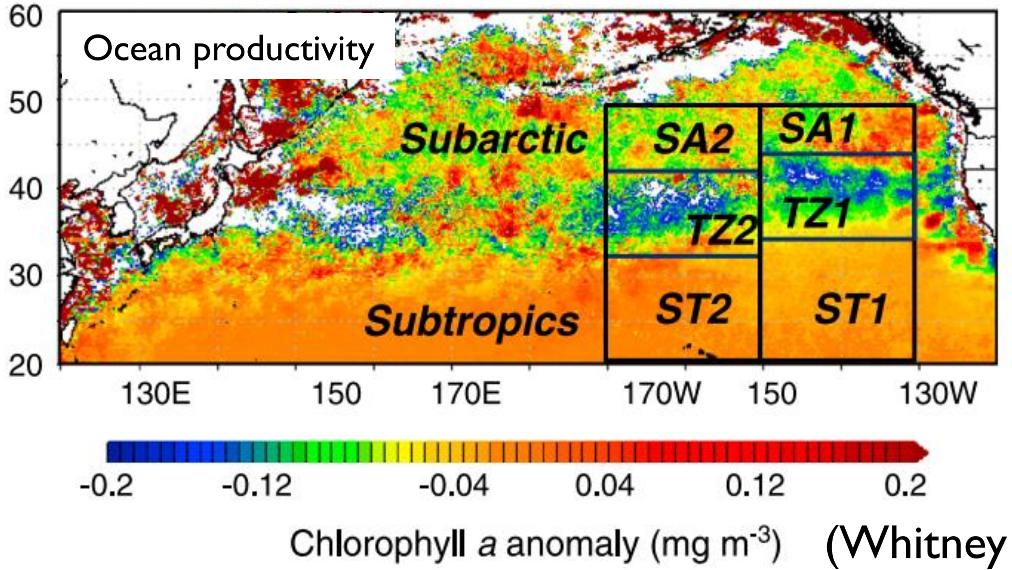


- Cold winter in North America (Hartmann 2015)

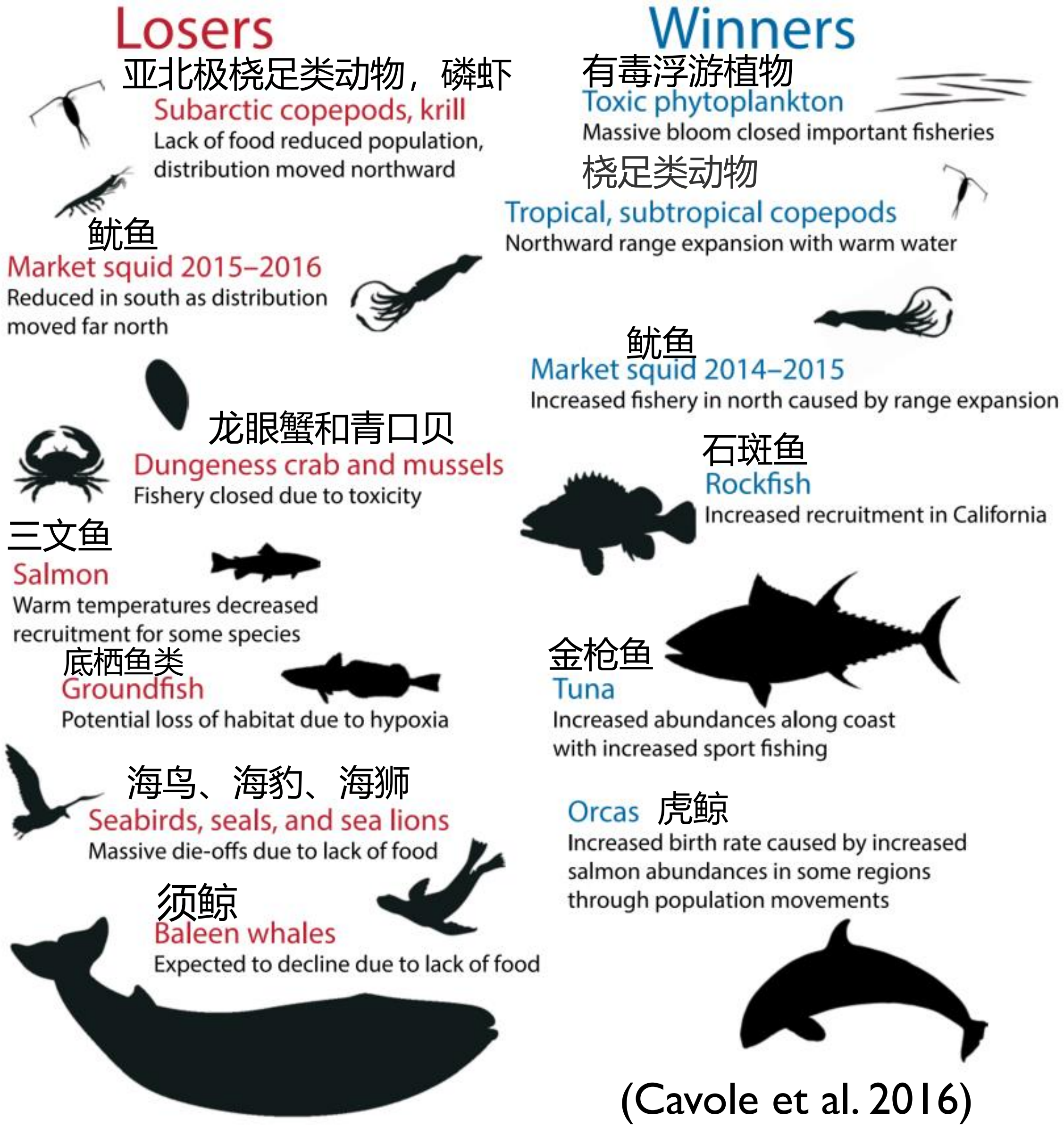


Ecosystem effects of "The Blob"



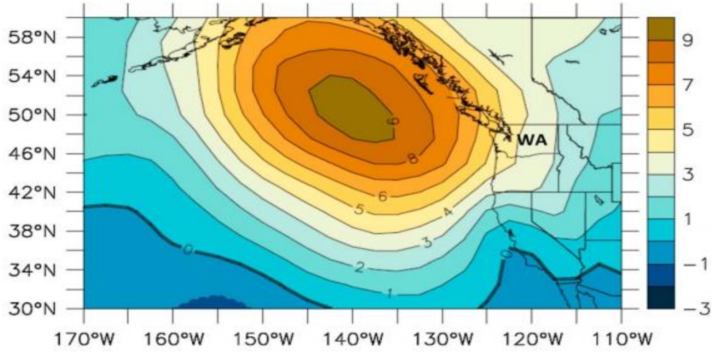


(Whitney 2015)

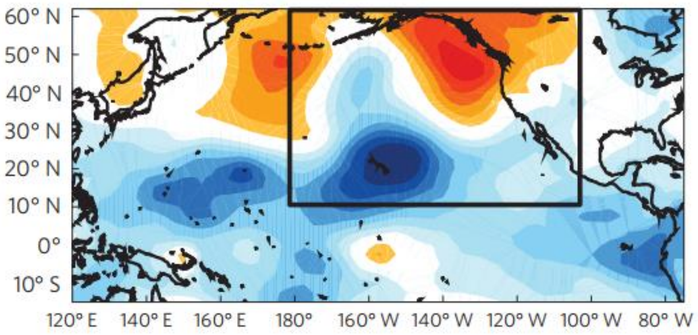


(Cavole et al. 2016)

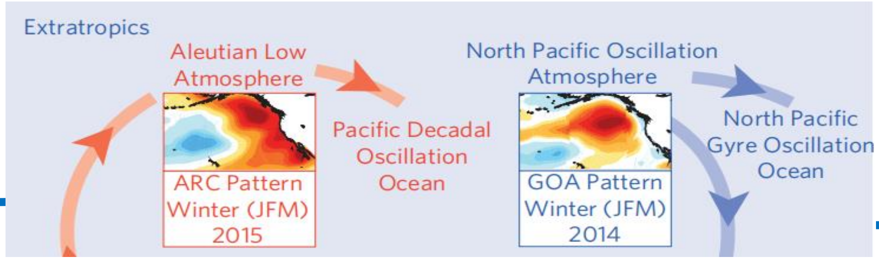
Mechanisms of "The Blob"



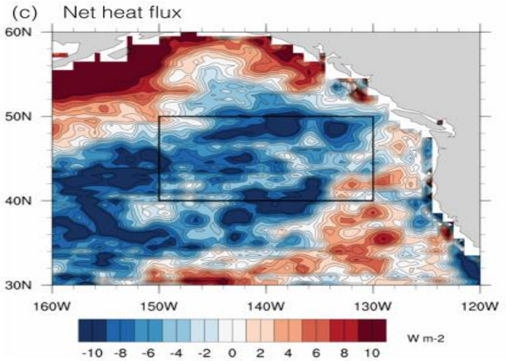
▪**atmospheric ridge**
(Bond et al. 2015)



▪**NPO-like circulation**
(Di Lorenzo and Mantua 2016)

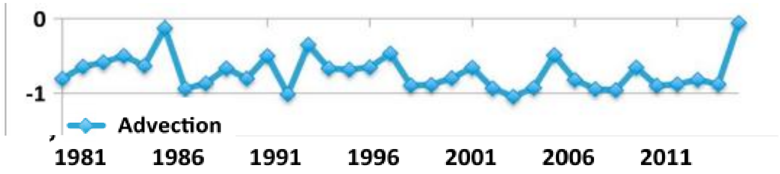


▪**coupling between NPGO and PDO**
(Di Lorenzo and Mantua 2016; Joh and Di Lorenzo 2017)

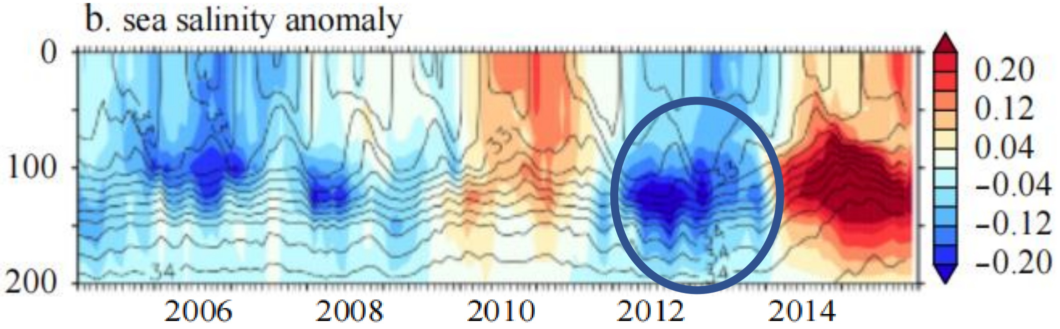


▪**surface heat flux**
(Schmeisser et al. 2019)

ocean surface



▪**ocean advection**
(Bond et al. 2015)

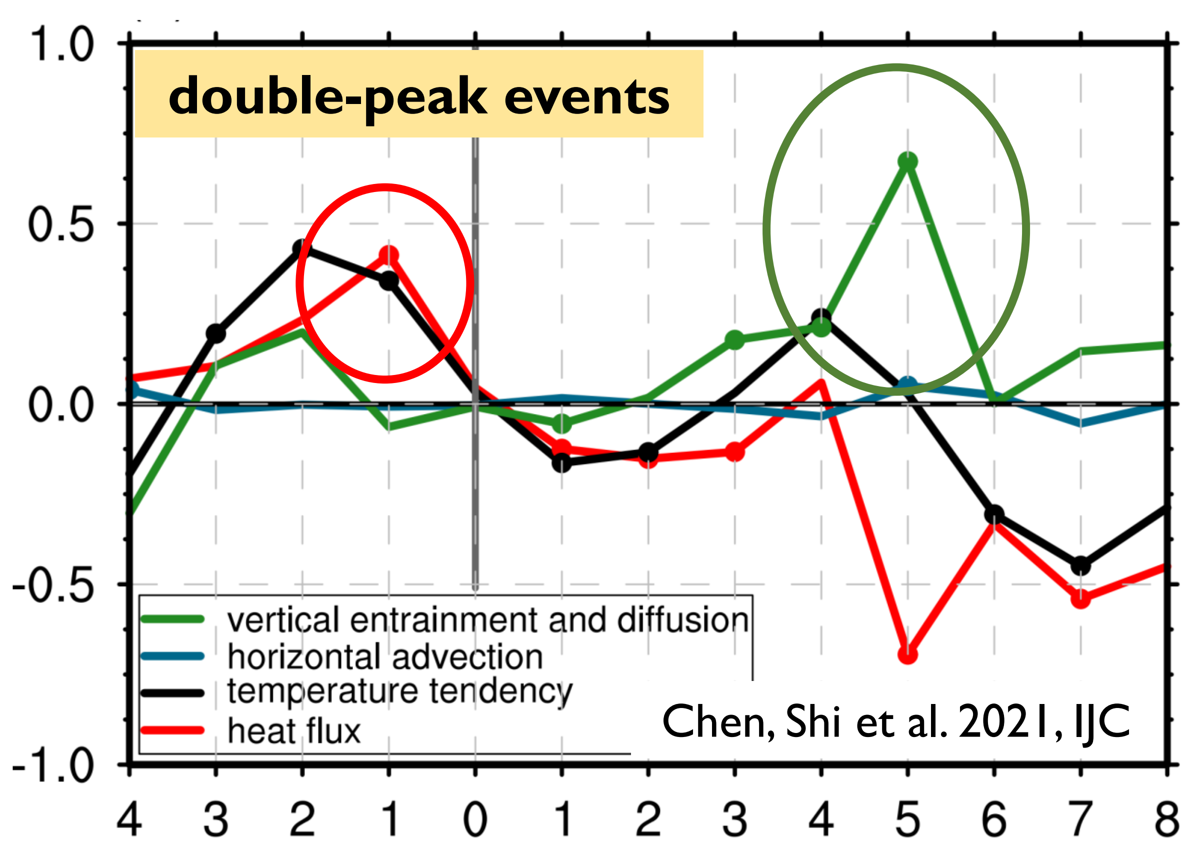


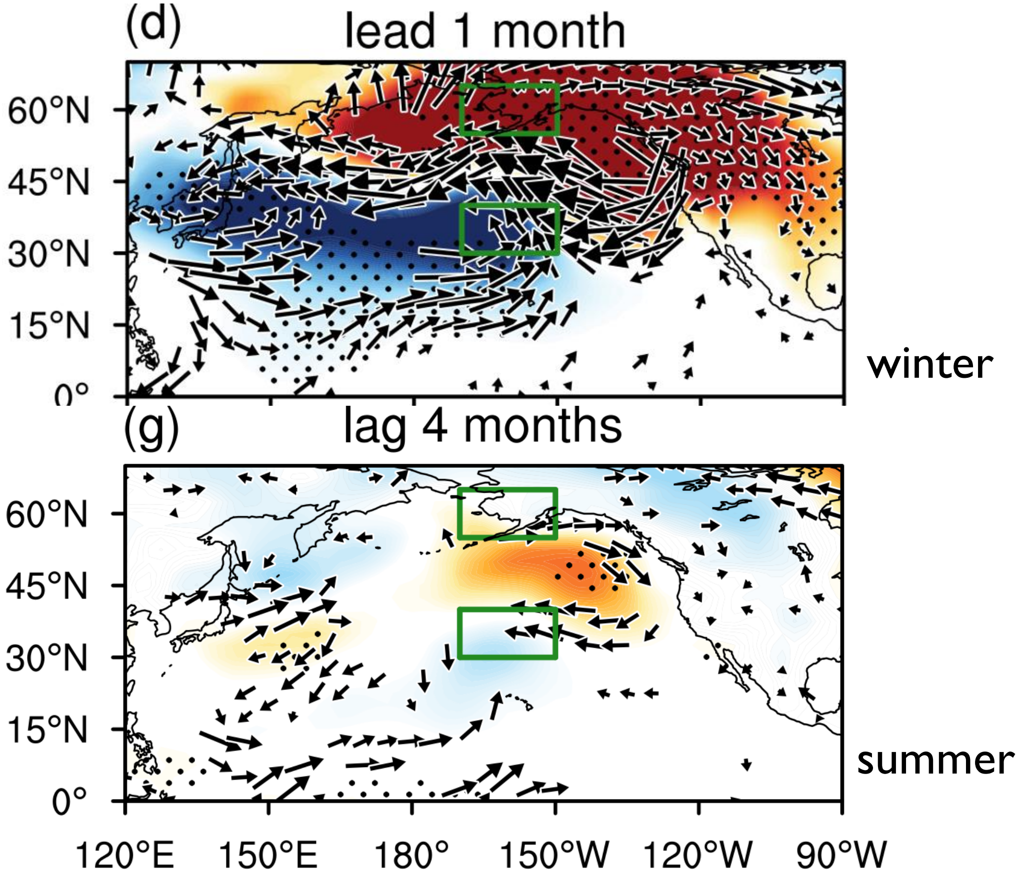
▪**salinity effects**
(Zhi et al. 2019)

Mechanisms of Northeast Pacific warm blobs

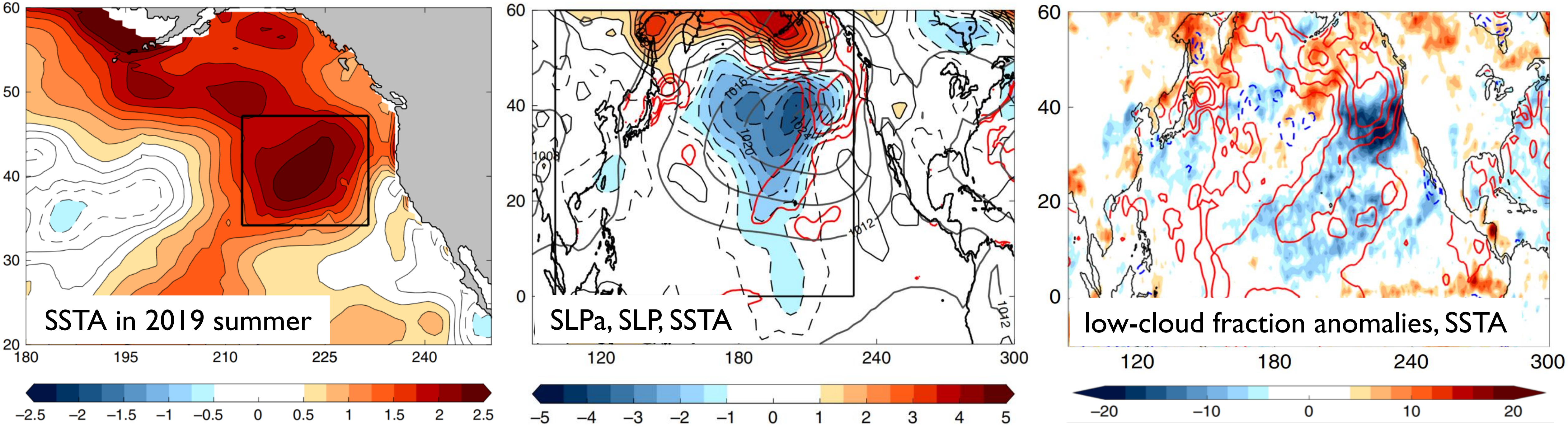
$$\frac{\partial}{\partial t}T = \frac{Q_0}{\rho C_p h} - u \cdot \nabla T - \left(w_h + \frac{dh}{dt}\right)\frac{(T - T_h)}{h} - \frac{k}{h}\frac{\partial T}{\partial z}\bigg|_{z=h}$$

temperature tendency = surface heat flux + horizontal advection + vertical entrainment + diffusion





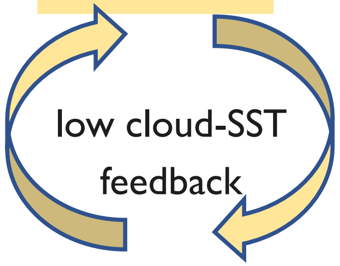
Mechanisms of Northeast Pacific warm blobs



weakening North Pacific high pressure → reducing surface winds →

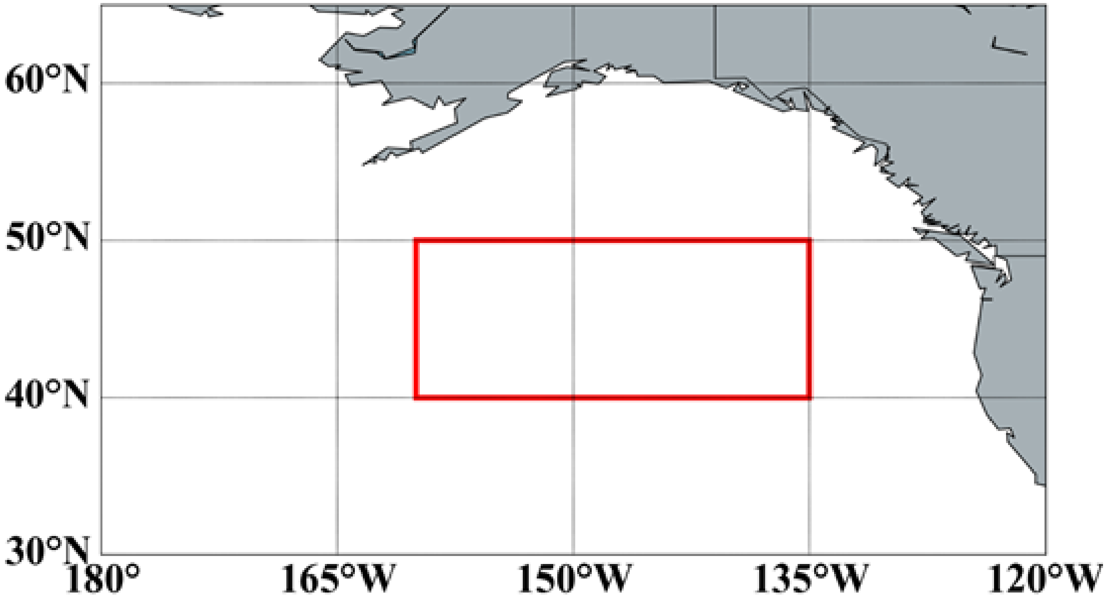
- decreasing evaporative cooling
- decreasing wind-driven upper ocean mixing and mixed layer depth

→ surface heat flux → Blob 2.0



(Amaya et al. 2020, NC)

Warm blob events



- **warm blob area:**

40°N–50°N, 160°W–135°W

- **warm blob index**

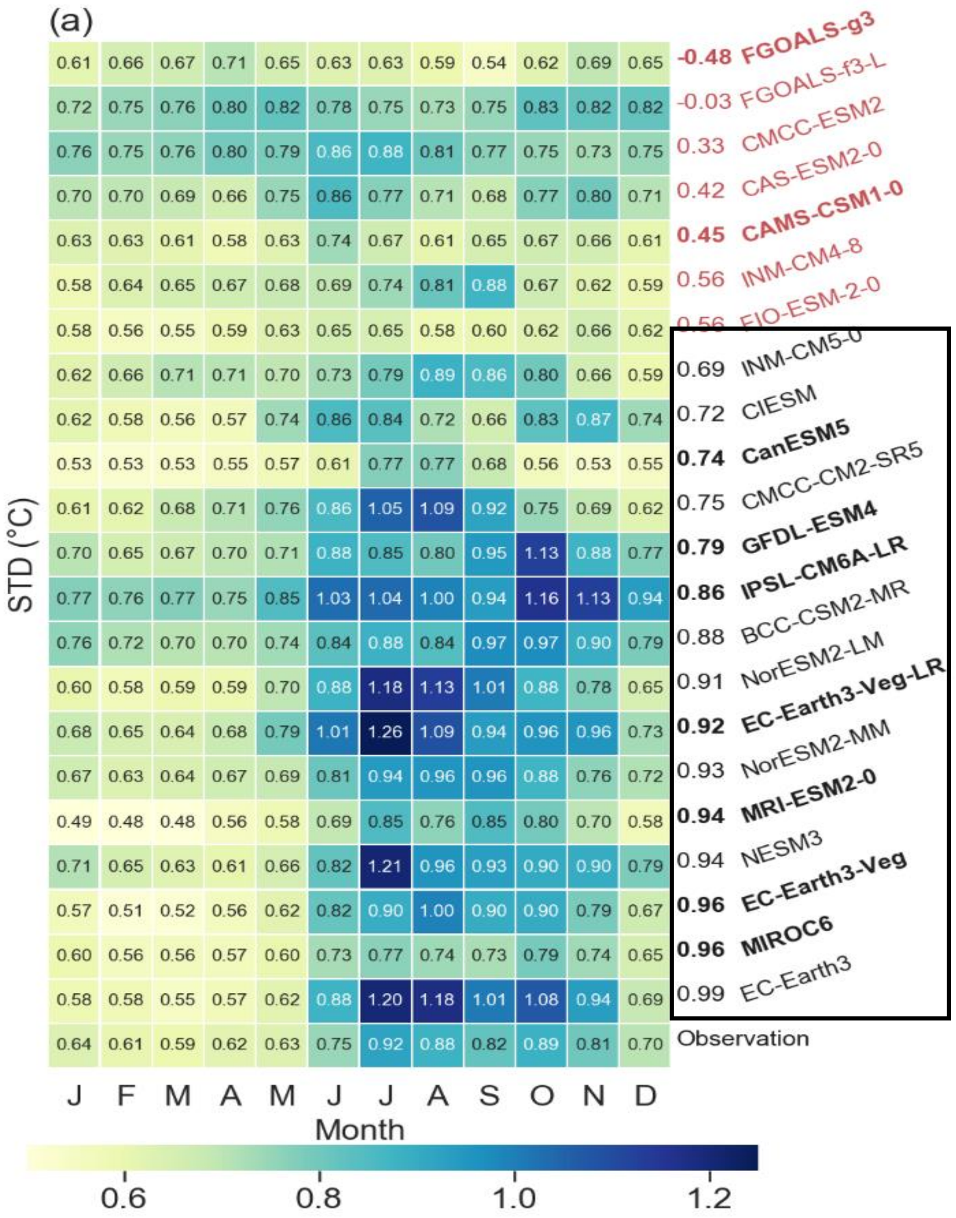
standardized monthly SST anomalies averaged over study area

- **warm blob event definition**

intensity threshold: larger than 0.75 of warm blob index

duration threshold: no fewer than 5 months with at most 1-month interruption

Model data



➢ **Model selection:**

- Capturing the **seasonality** of long-lived warm blobs in the NEP
- Correlations of monthly SST STD in the study area between historical simulations and observations are significant at 0.05 significance level

(Planton et al. 2018)

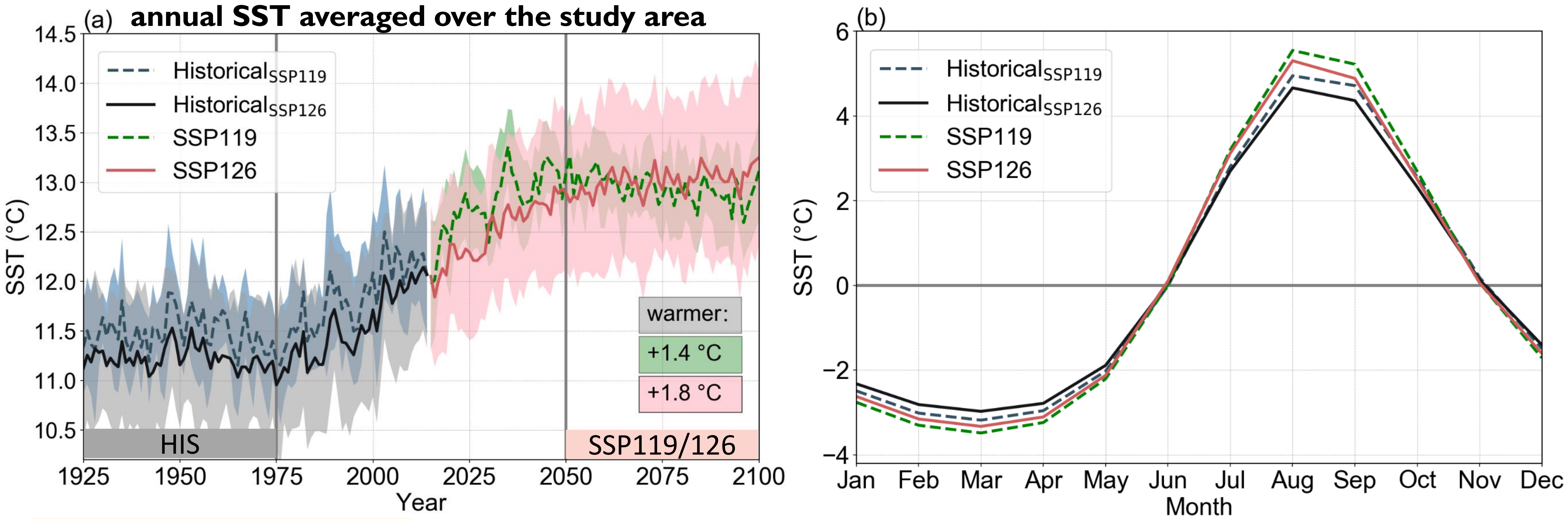
CMIP6 low-warming scenarios

- SSP119 scenario: 7 models
- SSP126 scenario: 15 models

-SSP1-1.9: 1.9W/m^2 forcing, 1.5℃ warming

-SSP1-2.6: 2.6W/m^2 forcing, 2.0℃ warming

Changes of temperature variability

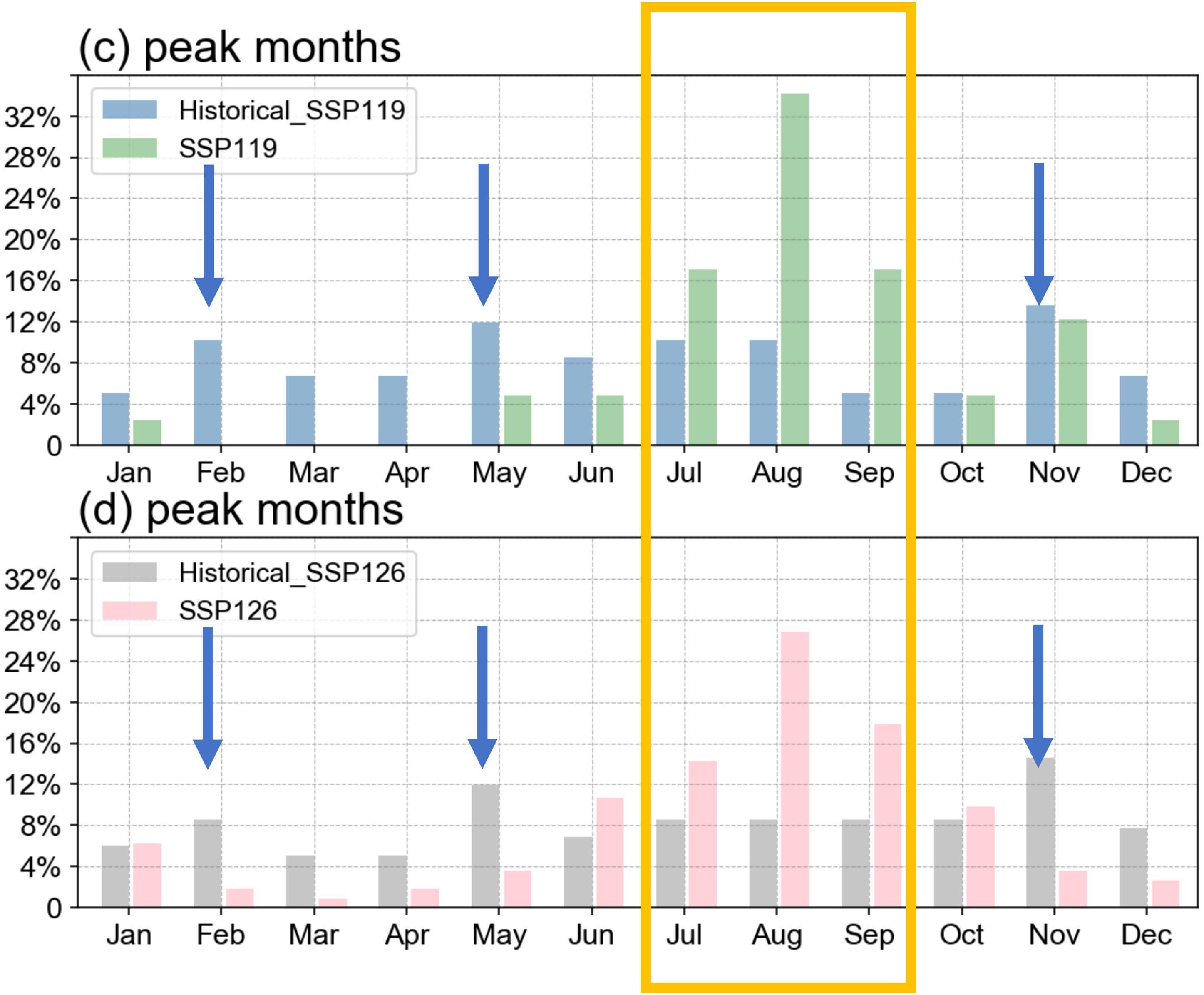


50-year for analysis

- HIS: 1925-1974
- SSP1-1.9: 2051-2100
- SSP1-2.6: 2051-2100

- The linear trends are removed for all the three periods
- Focusing on the effect of variability change on warm blob changes
- Amplification of seasonal cycle is identified in low-warming climates

Changes of timing of the warm blobs



➢ **historical scenario:**

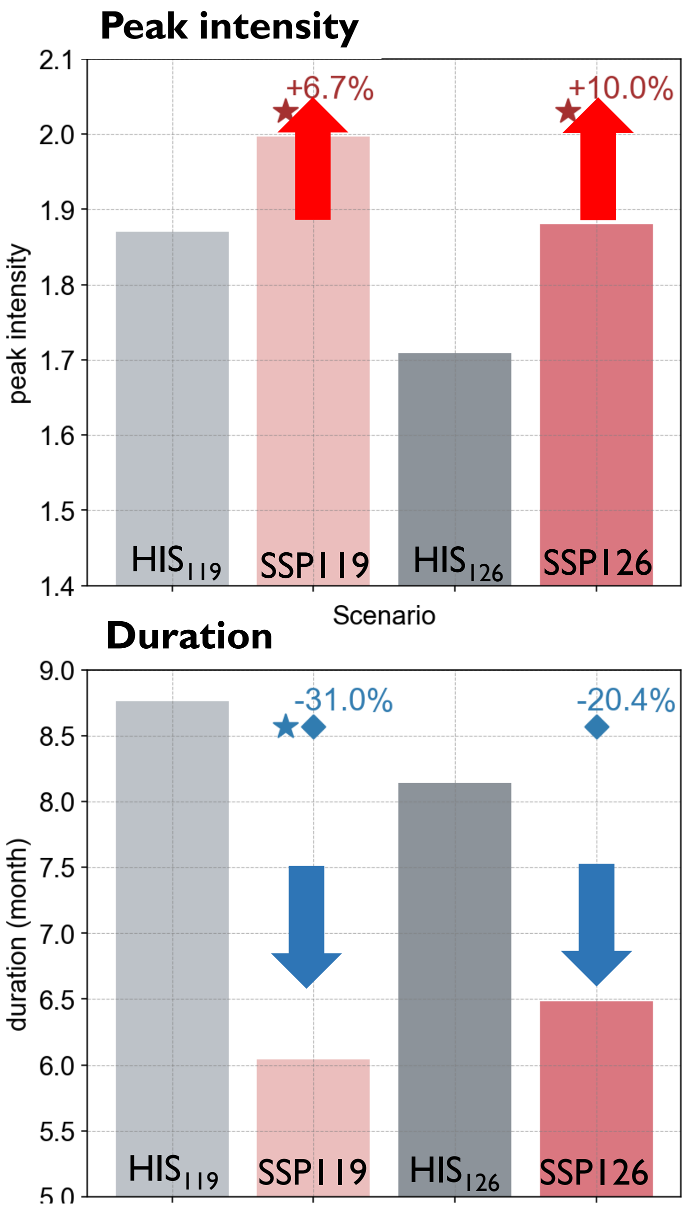
- Peaking more frequently in cold seasons
- November, February, and May

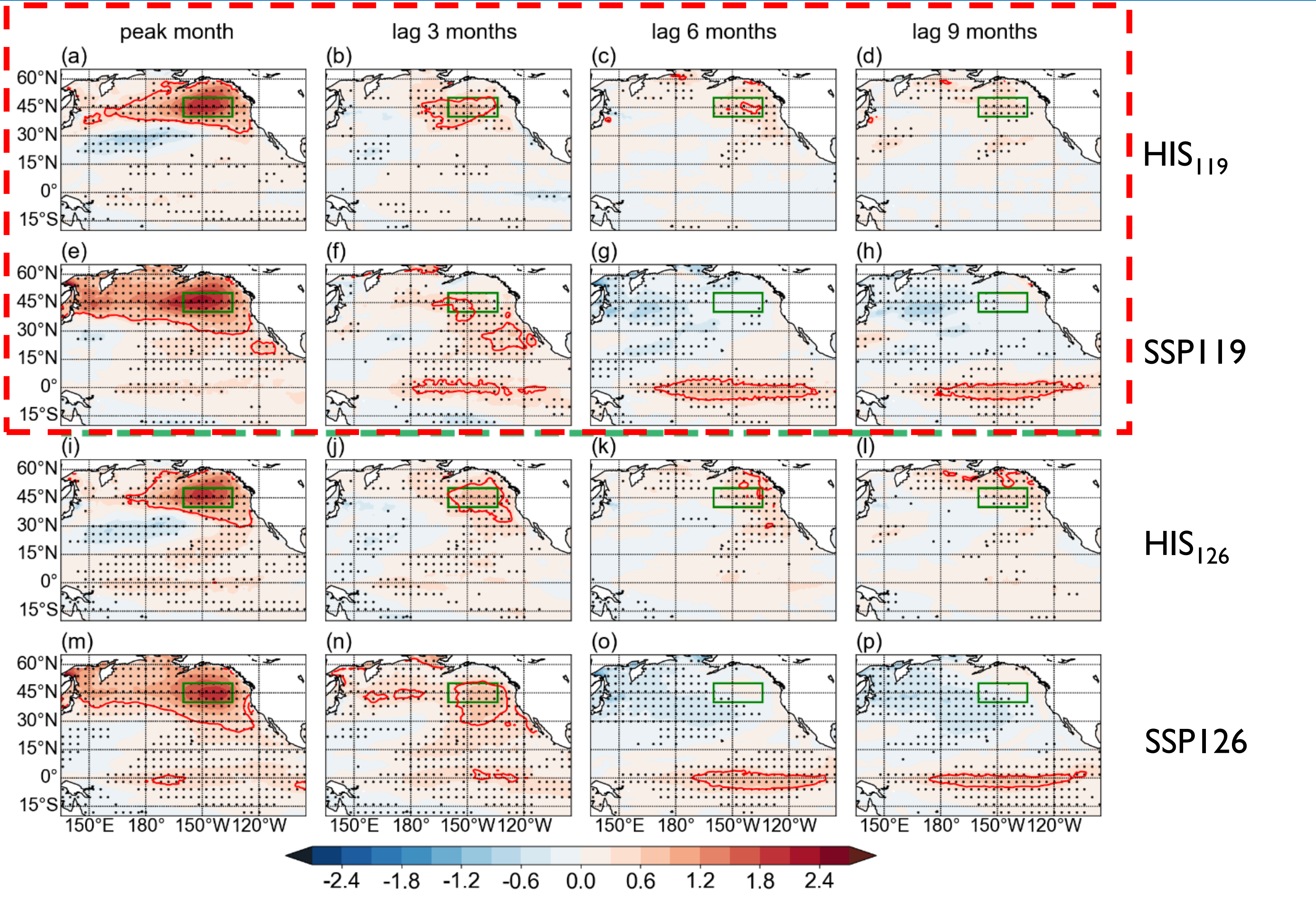
➢ **low-warming scenarios**

- Peaks shift to the boreal summer

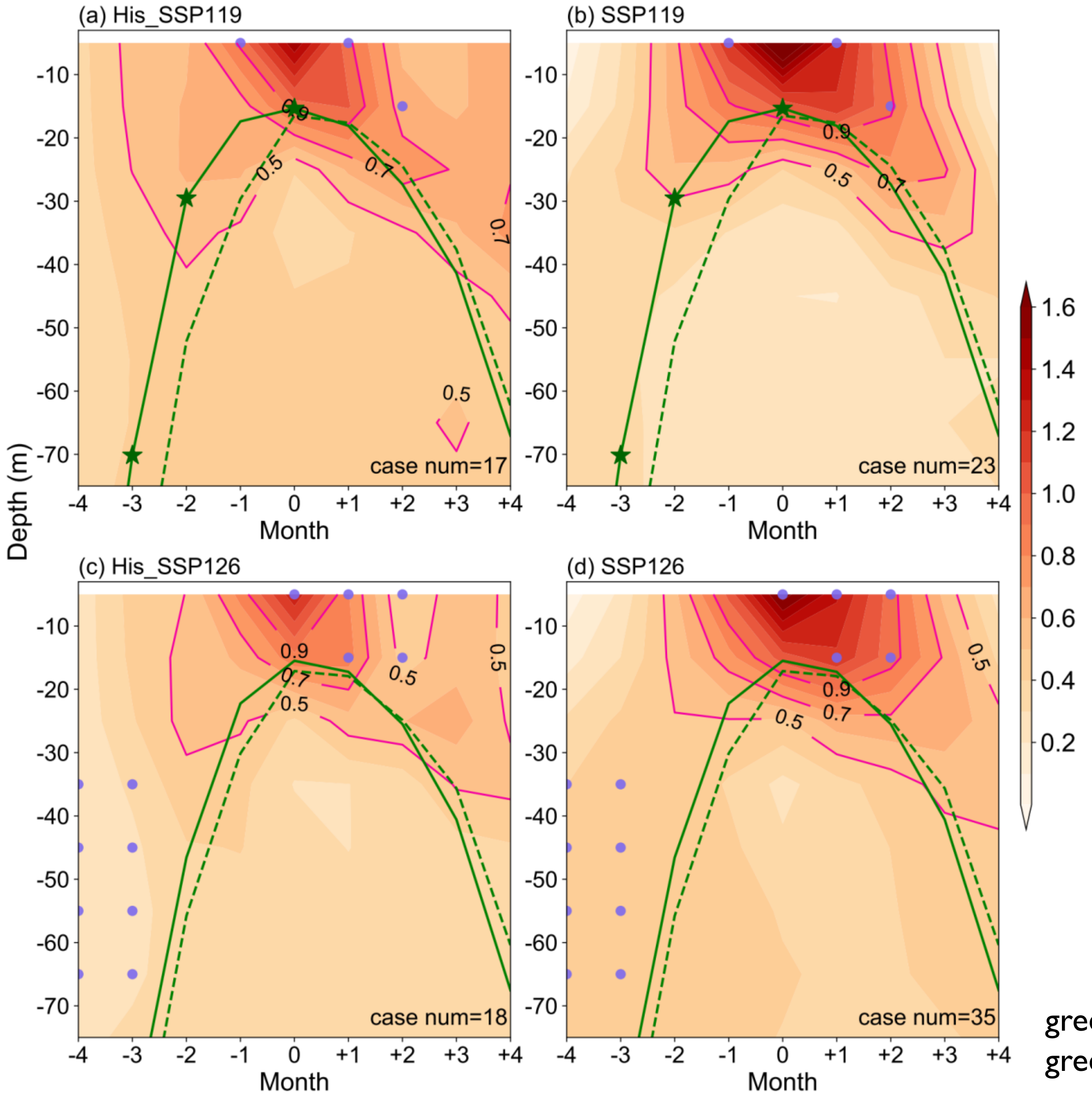
Focusing on summer-peak cases in the following results

Intensity and duration changes of warm blobs





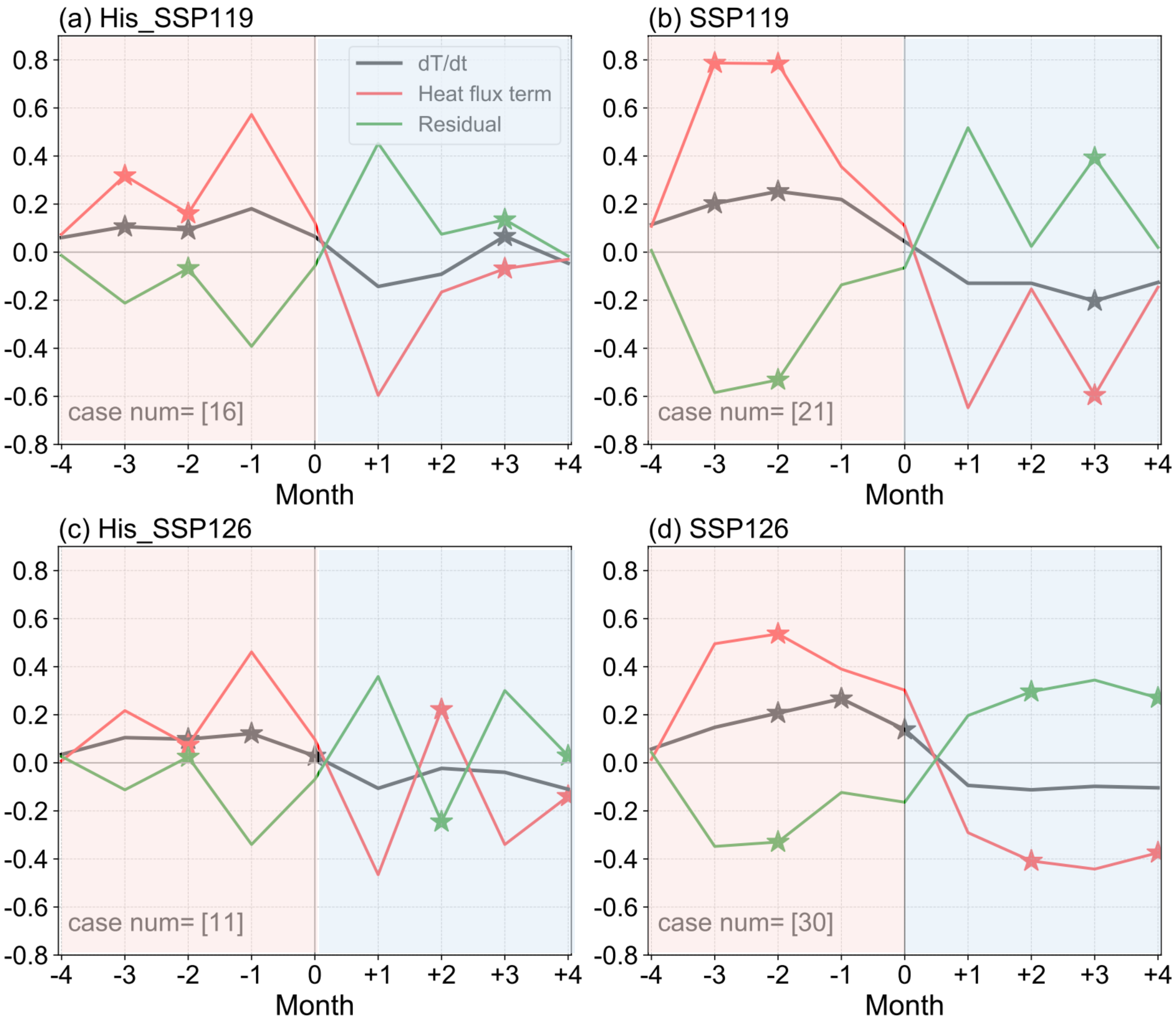
Changes of warm blobs in vertical distribution



- Stronger vertical temperature anomalies are identified under warming scenarios
- Significant shallower mixed layer depth is identified in spring and summer under SSP119 scenario

green-dashed lines: historical scenario
green-solid lines: warming scenario

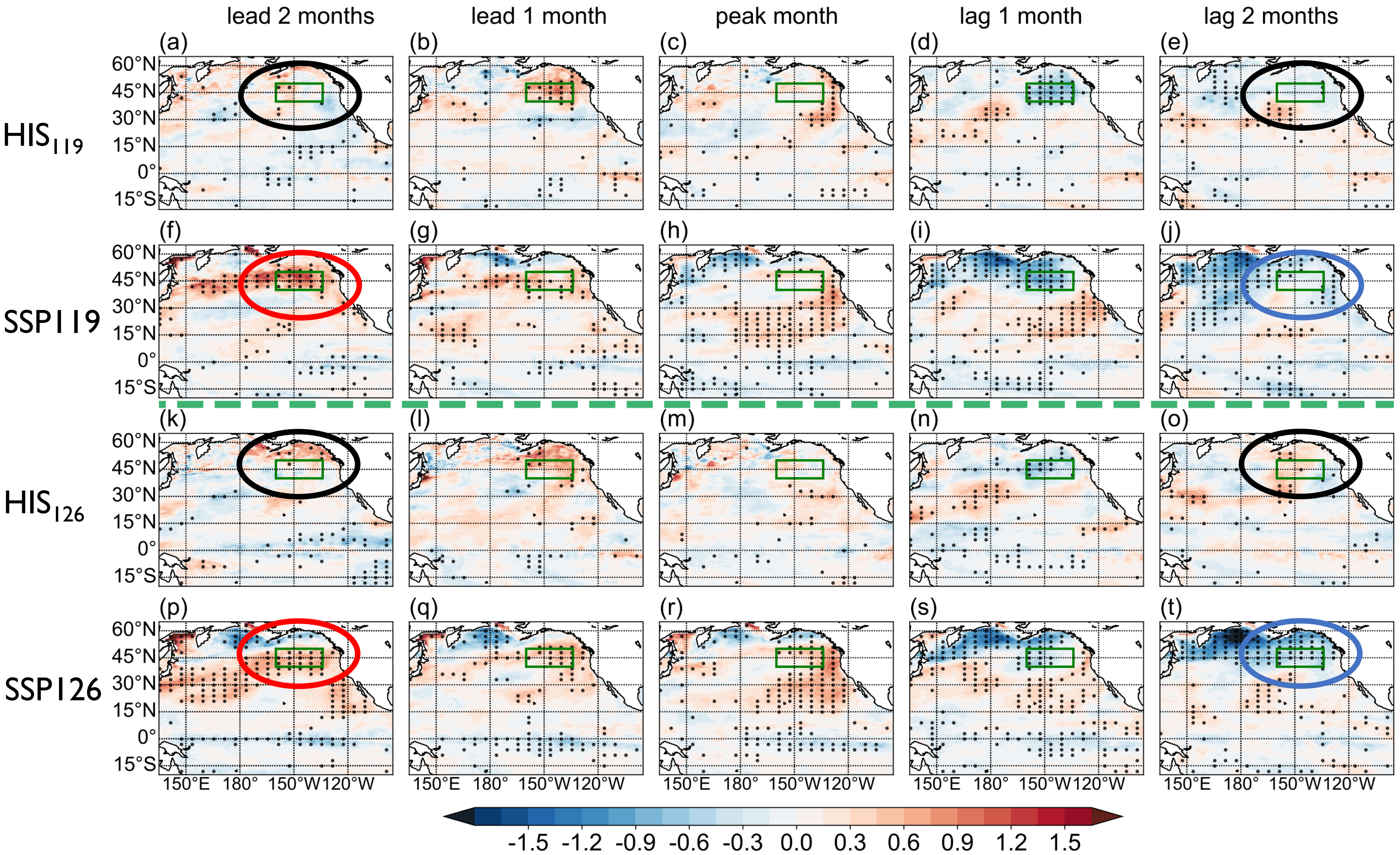
Mechanisms for future warm blob changes



- **development stage**
  - Surface heat flux anomalies dominate.
  - Warming scenarios have larger positive anomalies.

- **decay stage**
  - Surface heat flux anomalies dominate.
  - Warming scenarios have larger negative anomalies.

Warm blob changes: surface heat flux anomalies



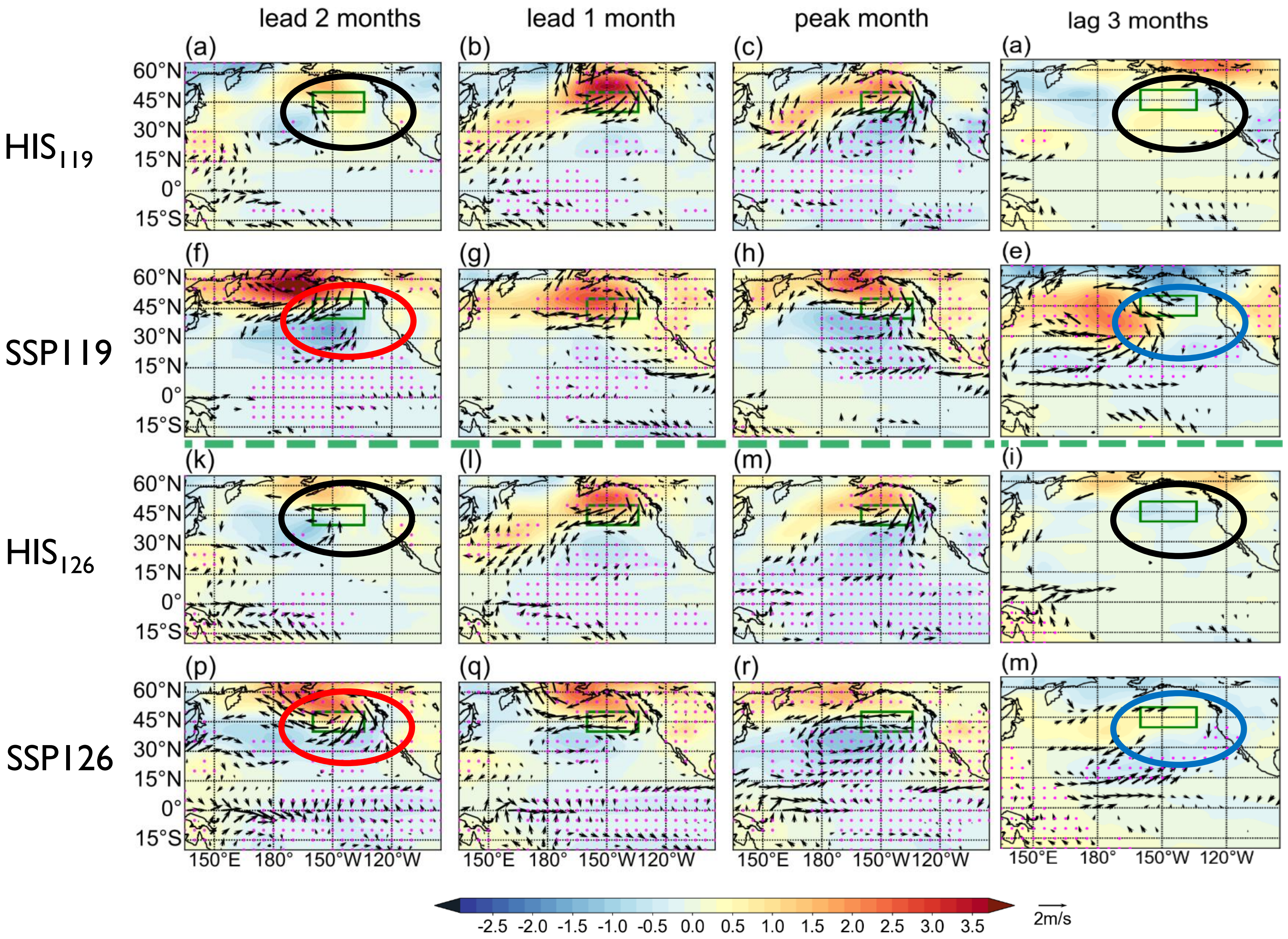
development stage

- Larger positive surface heat flux anomalies under warming scenarios

decay stage

- Larger negative surface heat flux anomalies under warming scenarios

Warm blob changes: surface wind and SLP anomalies



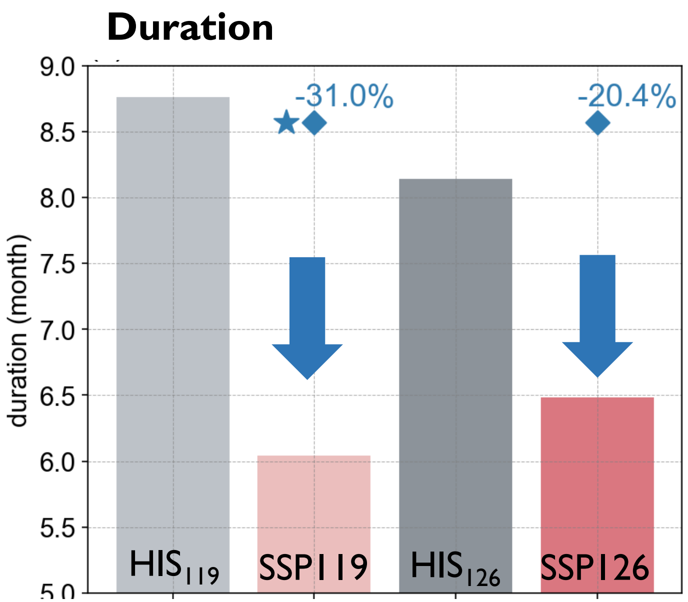
development stage

- Larger easterly anomalies under warming scenarios

decay stage

- Earlier westerly anomalies under warming scenarios

Warm blob duration and ocean memory



SCIENCE ADVANCES | RESEARCH ARTICLE

OCEANOGRAPHY

Global decline in ocean memory over the 21st century

Hui Shi[1]*, Fei-Fei Jin[2]*, Robert C. J. Wills[3], Michael G. Jacox[4,5], Dillon J. Amaya[5], Bryan A. Black[6], Ryan R. Rykaczewski[7,8], Steven J. Bograd[4], Marisol García-Reyes[1], William J. Sydeman[1]

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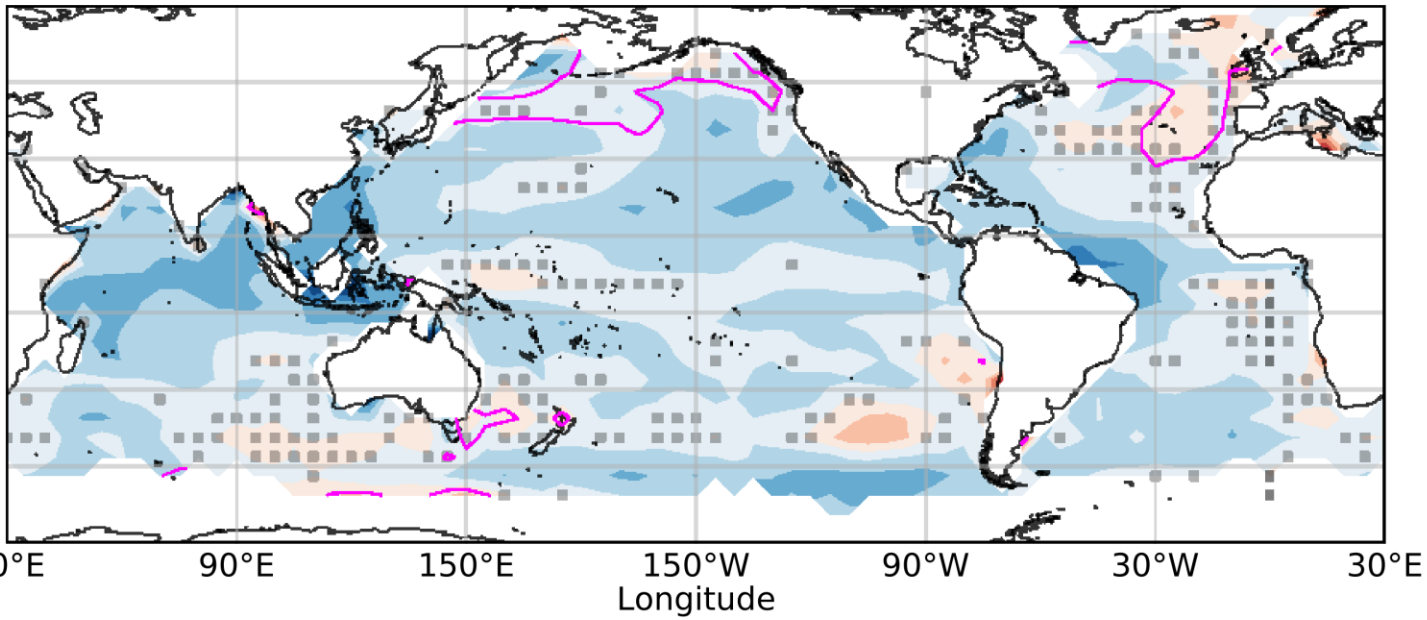


Key notes

potential changes in low-warming climates

- **timing of peaks**

shifting from cold seasons to summer

- **summer peak intensity**

SSP1-1.9: increasing by 6.7%

SSP1-2.6: increasing by 10.0%

- **duration**

SSP1-1.9: decreasing by 31.0%

SSP1-2.6: decreasing by 20.4%

- **potential mechanisms**

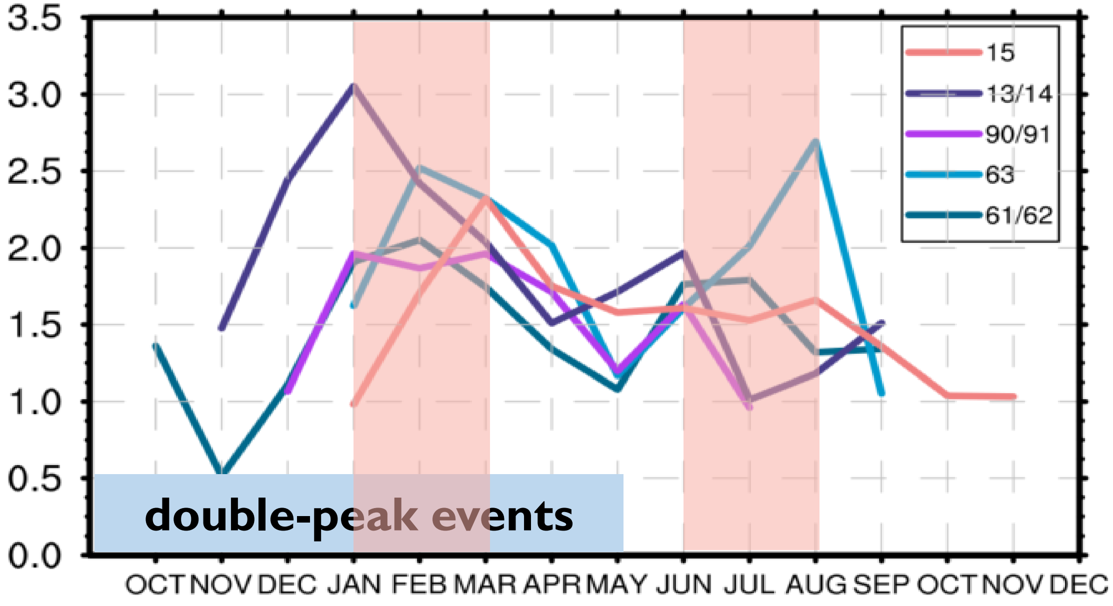
atmospheric processes dominate

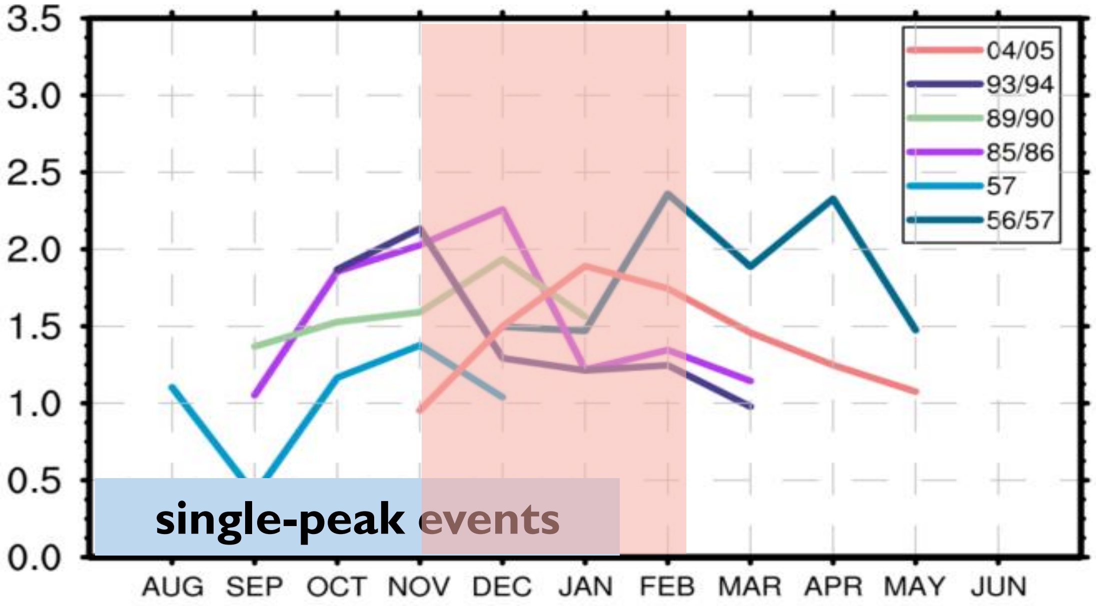
For more details, please refer to:

- Tang, C., **Shi, J.***, Wang, S., Zhang, Y., Lu, R., Li, C., Yu, T., Wang, R., Chen, Z. (2023). Changes and mechanisms of long-lived warm blobs in the Northeast Pacific in low-warming climates. Journal of Climate, 36, 2277–2292.

Thanks for your listening.

Two types of warm blob events over 1951-2018





Characteristics of double-peak events

- They have a salient amplification at least 2 months after the first peak.
- average duration: ~10 months
- first peak: boreal winter
- second peak: following summer

Characteristics of single-peak events

- They have only one robust peak
- average duration: 6 months
- first peak: boreal winter

(Chen, Shi et al. 2021, IJC)

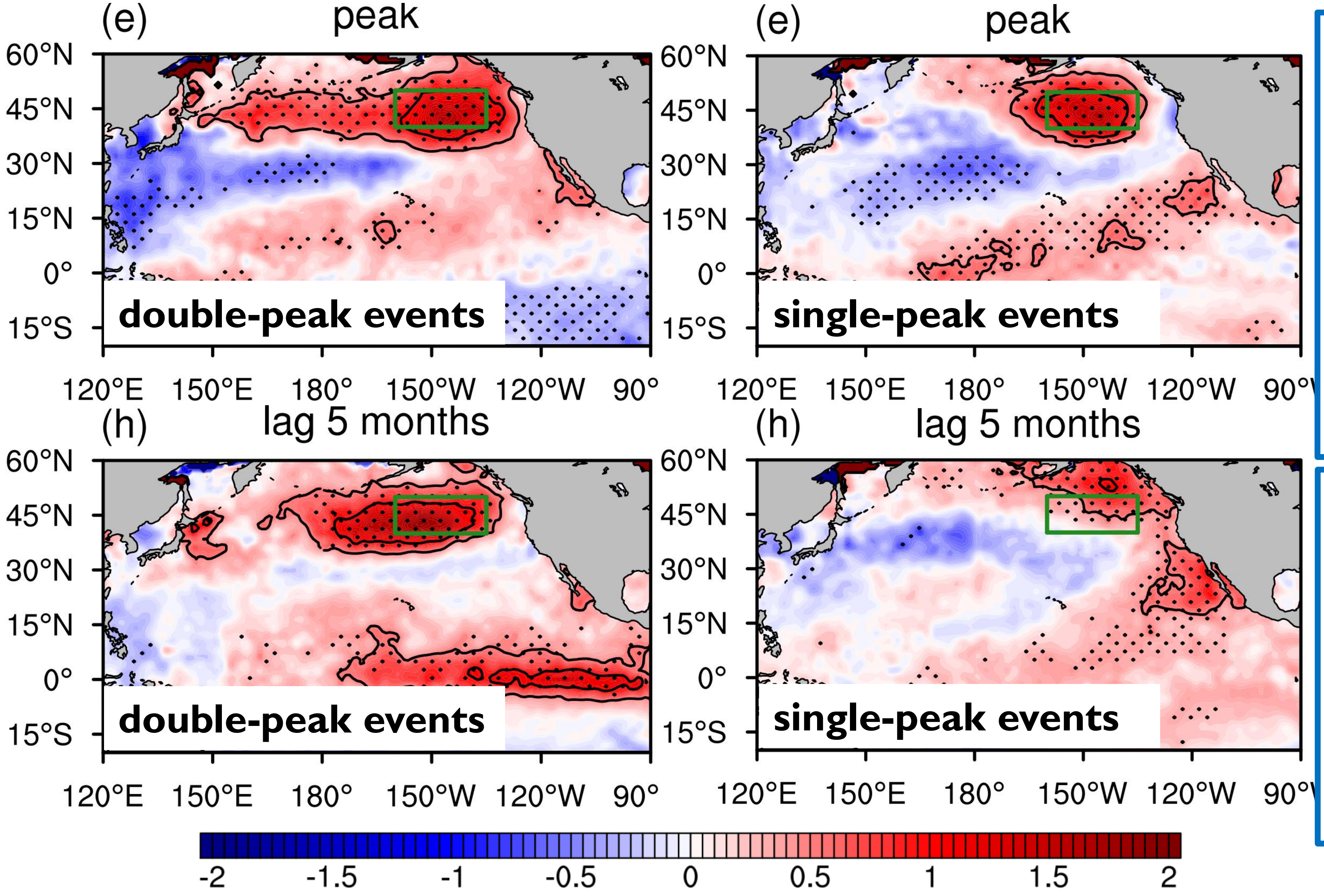
information of warm blob events

Start time	End time	Duration	Peak time	Peak intensity	Average intensity	Average NPGO
OCT 1961	SEP 1962	12	FEB 1962 JUL 1962	2.1 1.8	1.4	−0.1
JAN 1963	SEP 1963	9	FEB 1963 AUG 1963	2.5 2.7	1.9	−0.5
DEC 1990	JUL 1991	8	JAN 1991 JUN 1991	2.0 1.6	1.5	−0.6
NOV 2013	SEP 2014	11	JAN 2014 JUN 2014	3.1 2.0	1.8	−0.5
JAN 2015	NOV 2015	11	MAR 2015 AUG 2015	2.3 1.7	1.5	−1.4
Average				2.4* 2.0*	1.6*	−0.6*

Start time	End time	Duration	Peak time	Peak intensity	Average intensity	Average NPGO
DEC 1956	MAY 1957	6	FEB 1957	2.4	1.8	−1.3
AUG 1957	DEC 1957	5	NOV 1957	1.4	1.0	−1.0
SEP 1985	MAR 1986	7	NOV 1985	2.0	1.6	−1.2
SEP 1989	JAN 1990	5	DEC 1989	1.9	1.6	0.2
OCT 1993	MAR 1994	6	NOV 1993	2.1	1.5	−2.2
NOV 2004	MAY 2005	7	JAN 2005	1.9	1.4	−1.2
Average				2.0*	1.5*	−1.1*

Chen, Shi et al. 2021, IJC

SST anomaly pattern of warm blobs



double-peak events

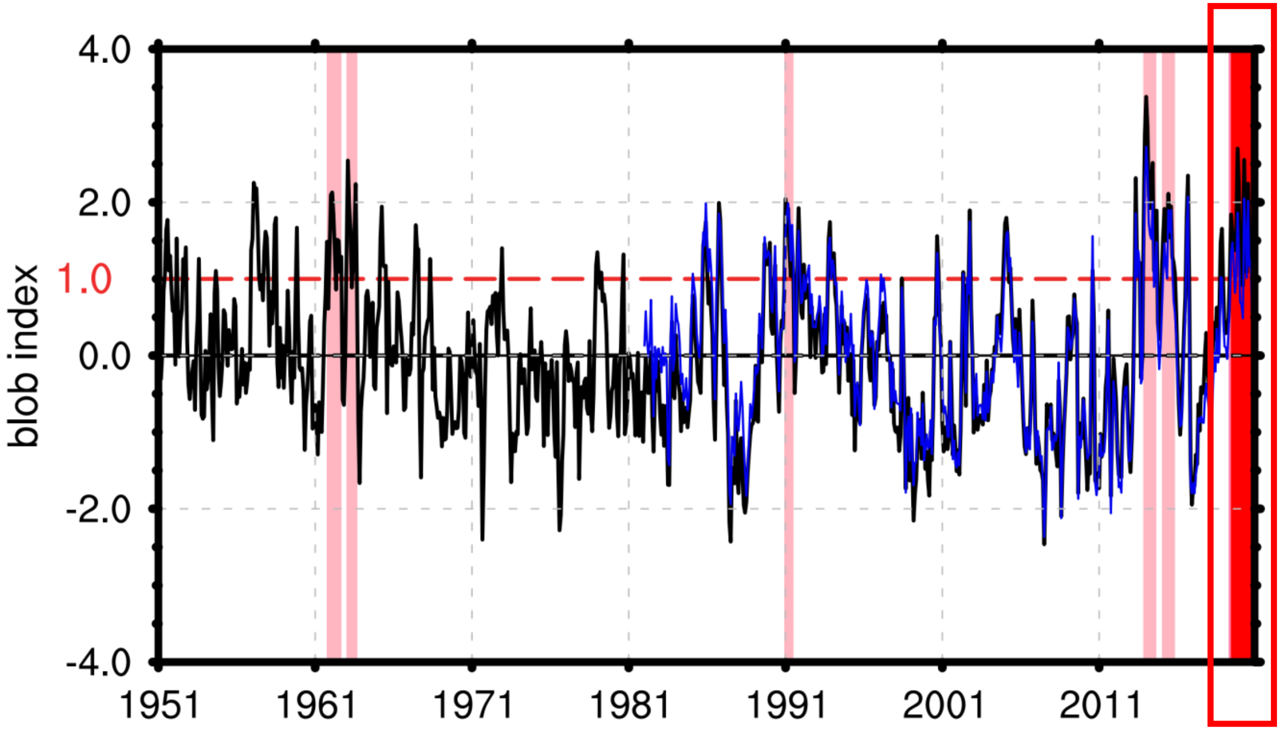
- stronger SST anomaly
- extend zonally
- re-intensify with a second peak
- NPGO-like expression

single-peak events

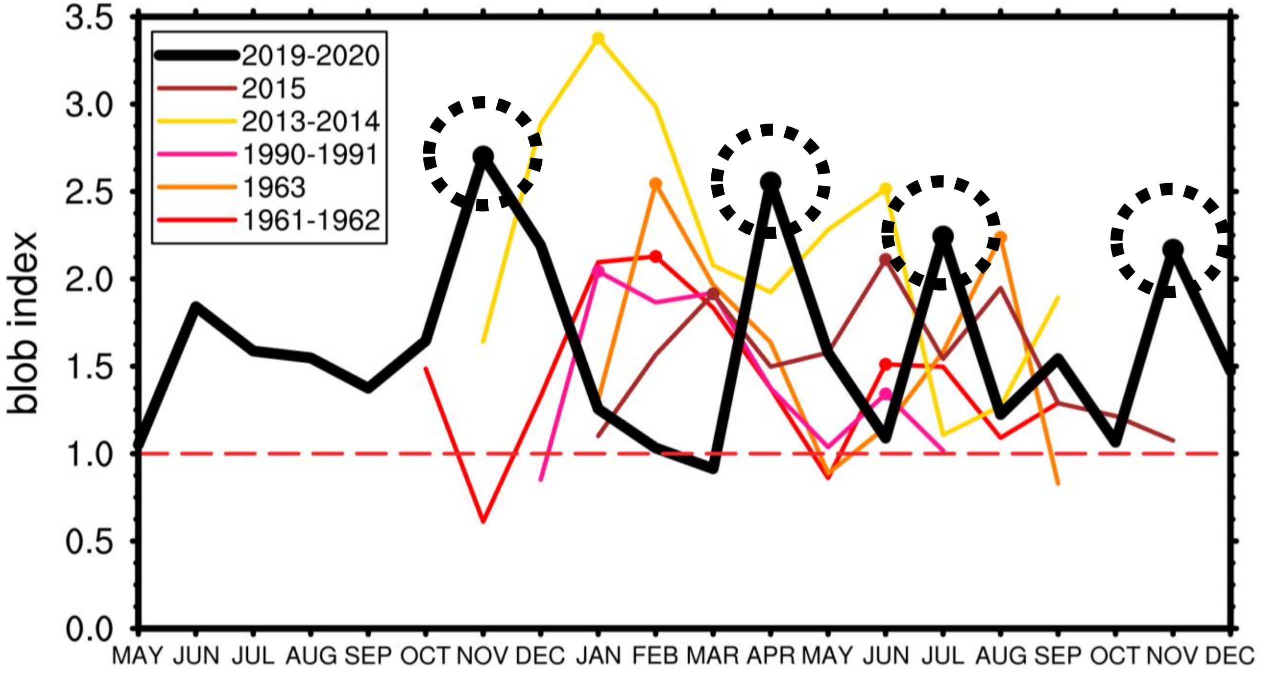
- weaker SST anomaly
- more locally
- decay along NA coast
- NPGO-like expression

(Chen, Shi et al. 2021, IJC)

The persistent warm blob over 2019-2020

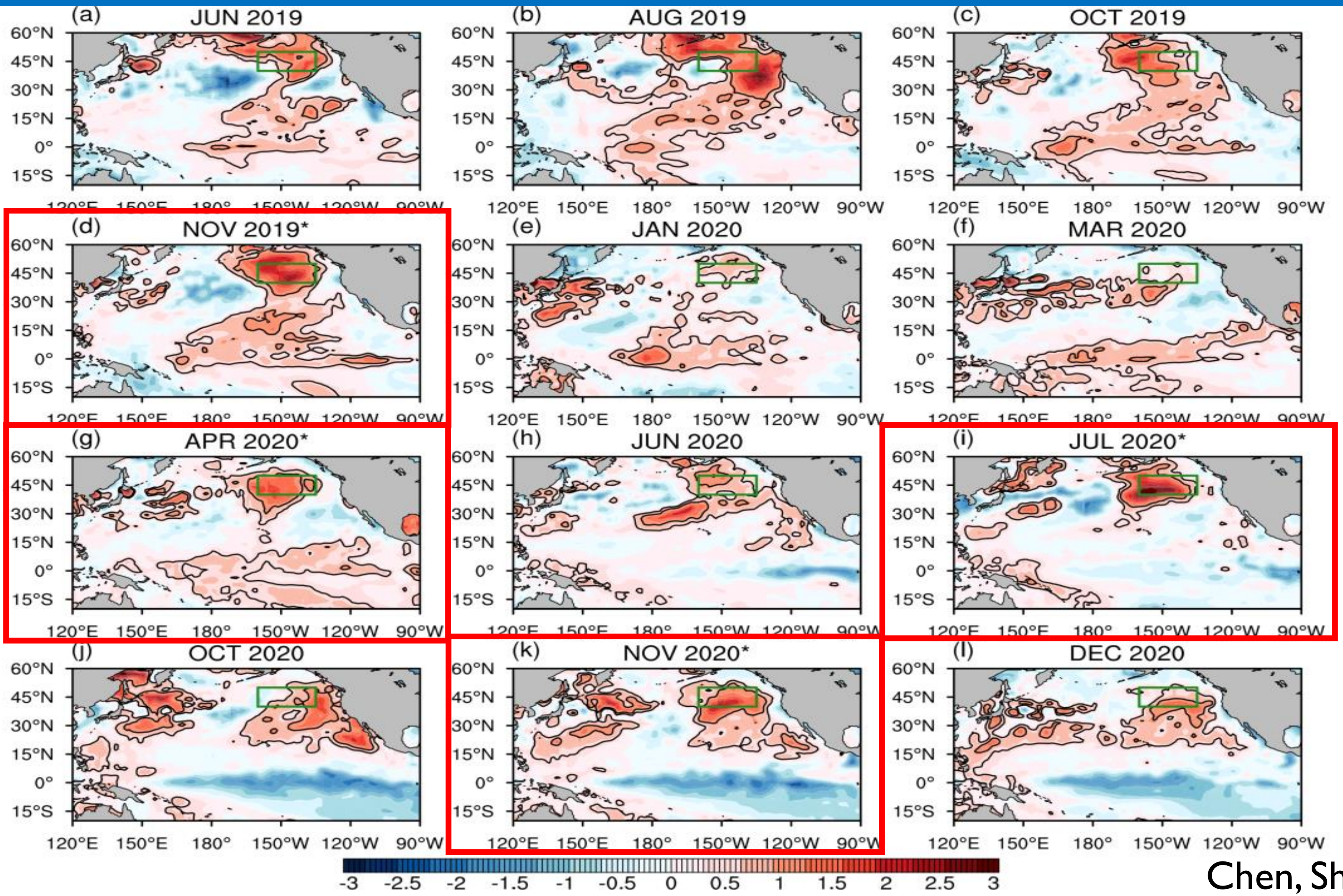


Chen, Shi et al. 2021, GRL



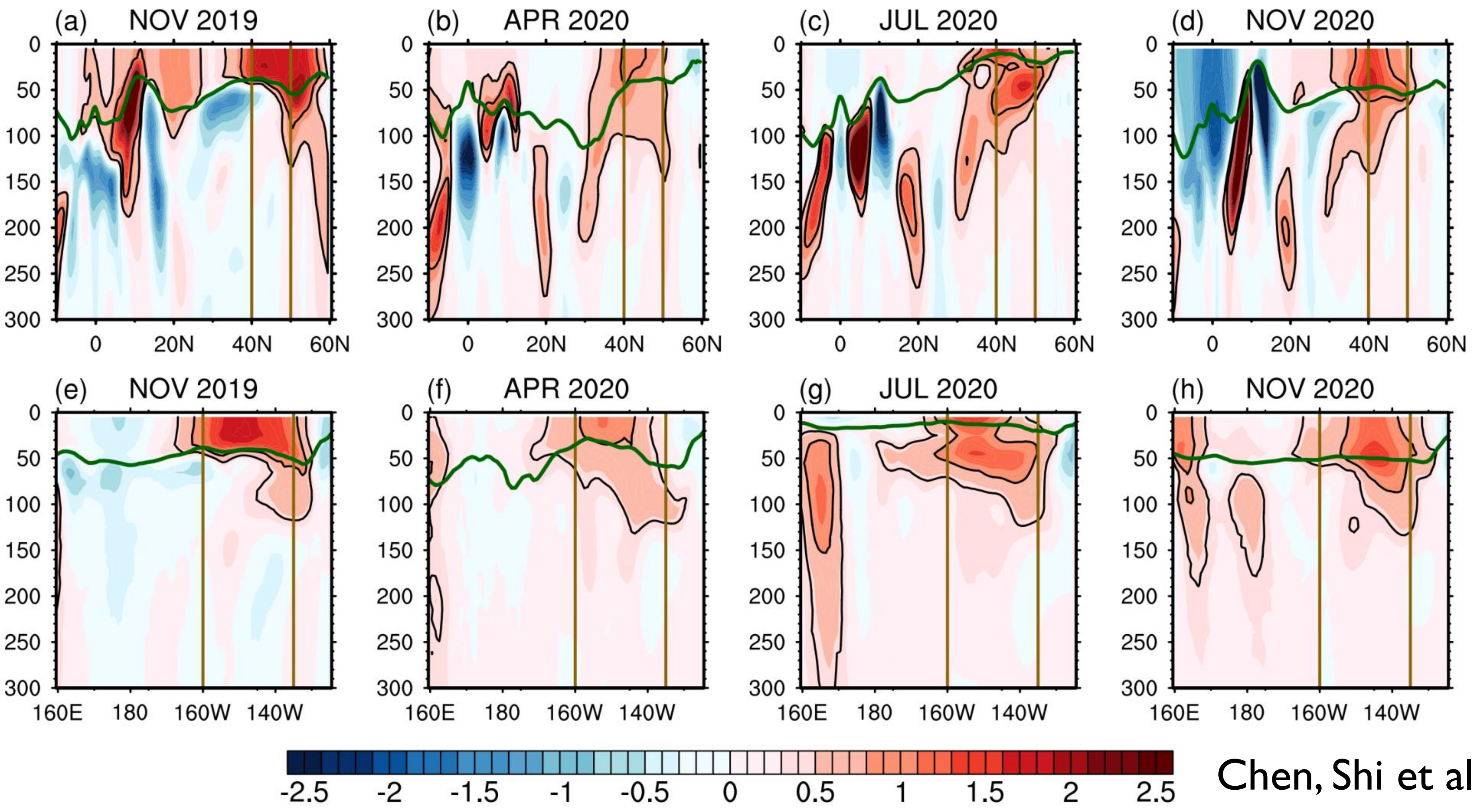
- **Duration:** longest event with a 20-month duration from May 2019 to December 2020
- **Intensity:** second strongest case
- **Multi-peak:** four peaks in the evolution

Horizontal evolution of SSTA for 2019-20 warm blob



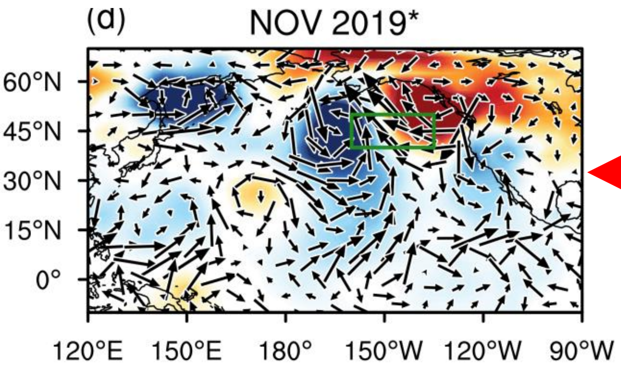
Chen, Shi et al. 2021, GRL

Vertical temperature evolution of 2019-20 warm blob

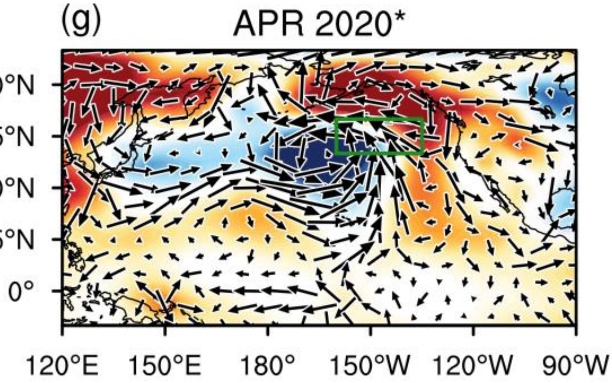


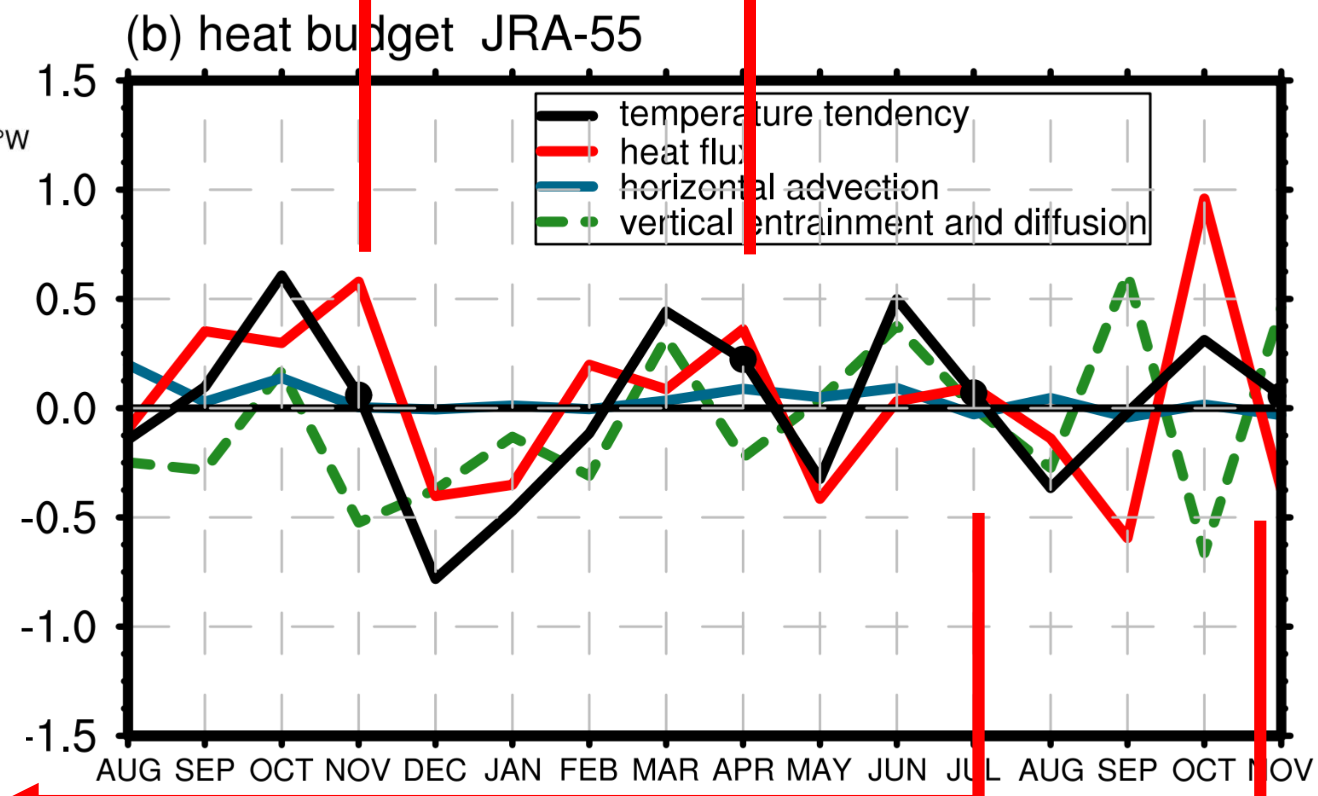
Chen, Shi et al. 2021, GRL

Driving factors of 2019-2020 warm blob

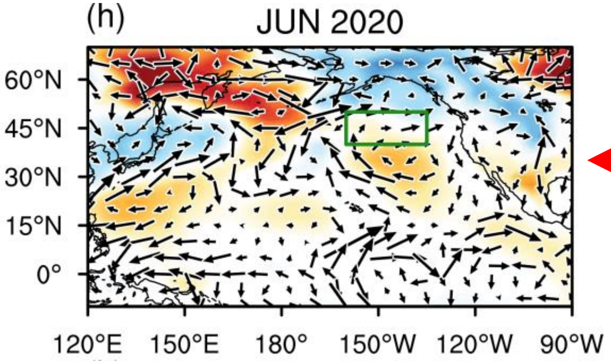


- **first winter peak and spring peak**
  Prevailing easterly anomalies



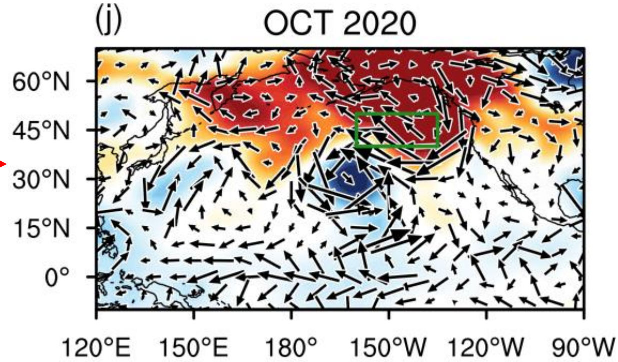


Chen, Shi et al. 2021, GRL

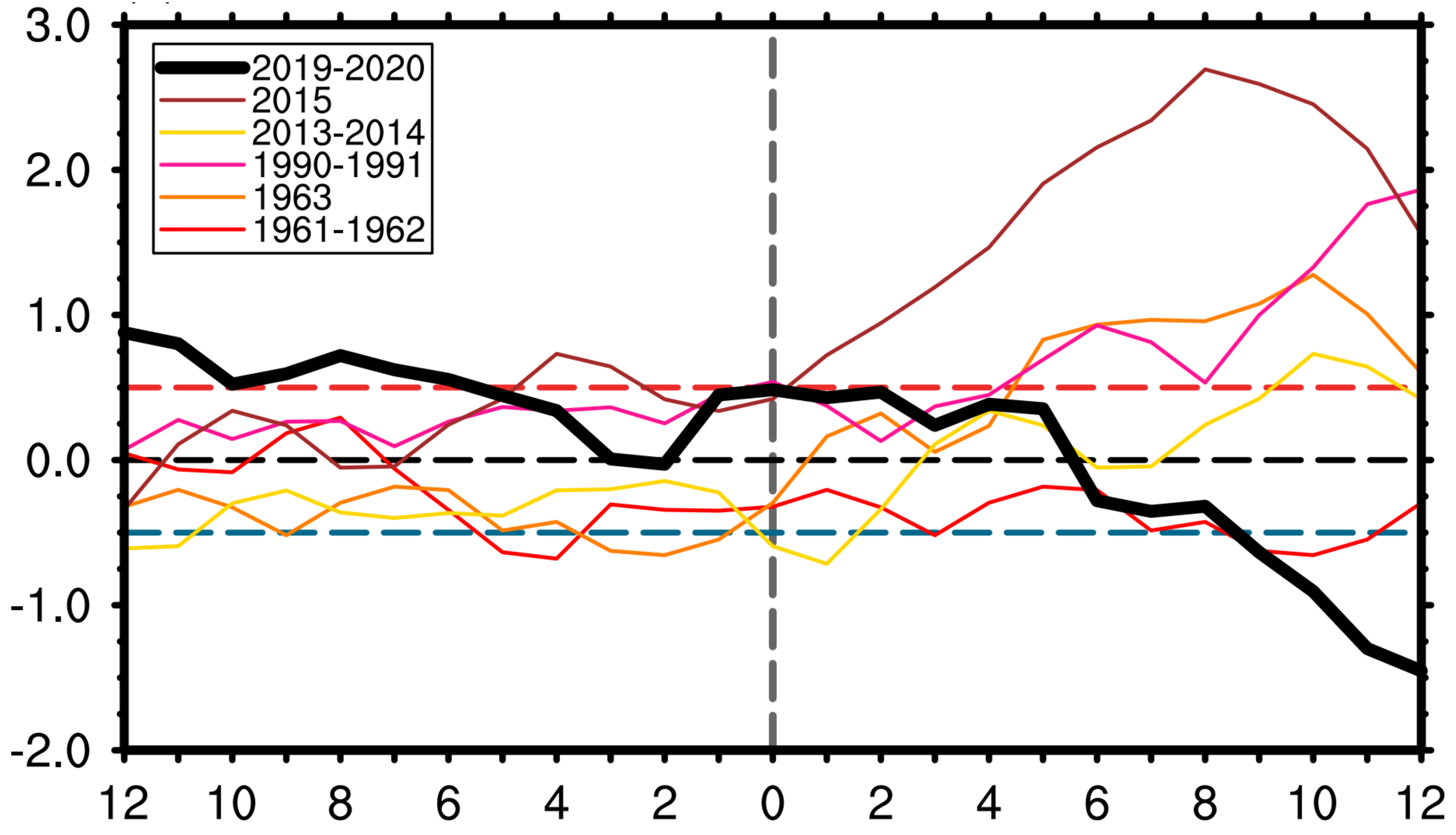


- **summer peak**
  Weak westerly anomalies

- **second winter peak**
  Prevailing easterly anomalies

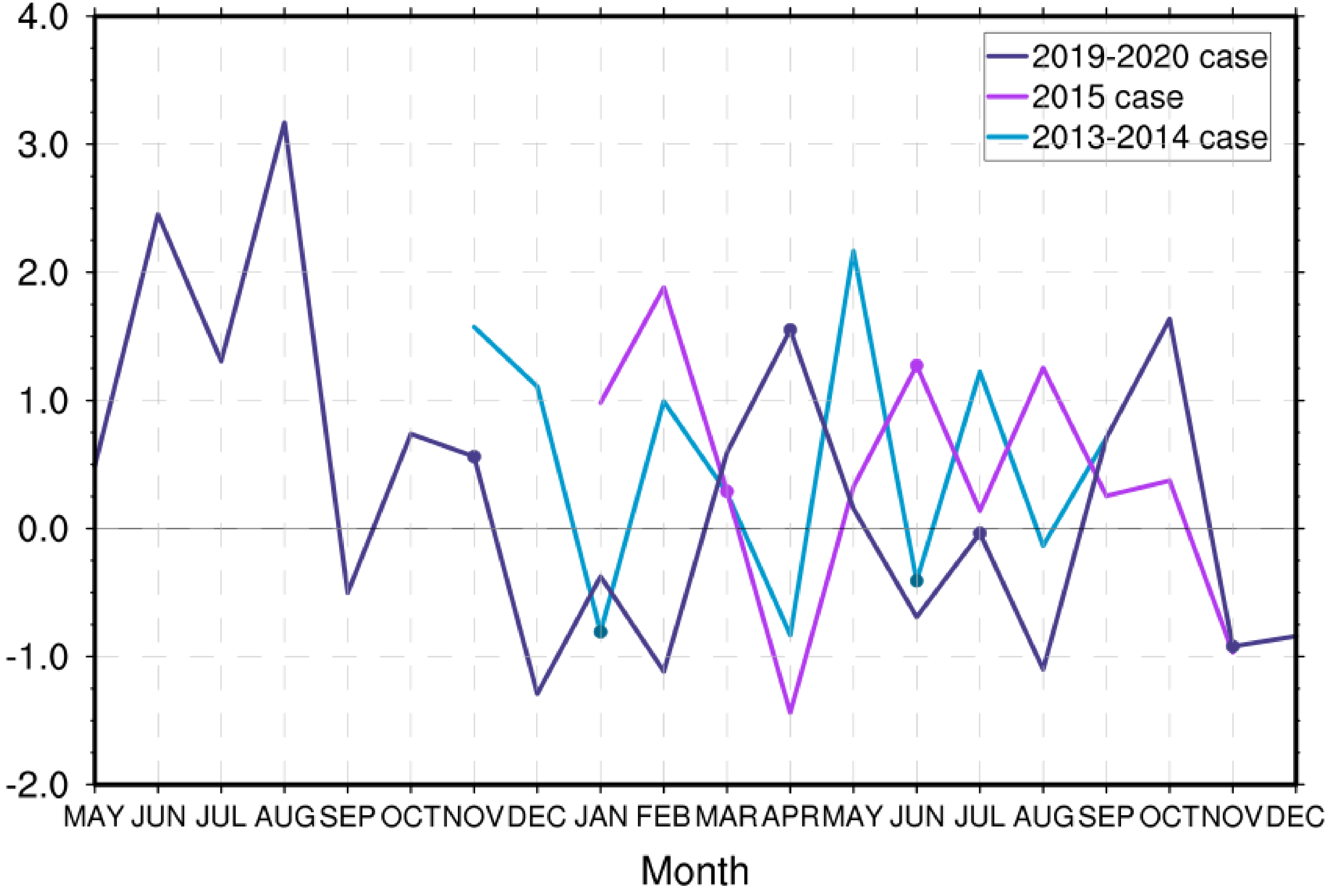


Nino3.4 evolution



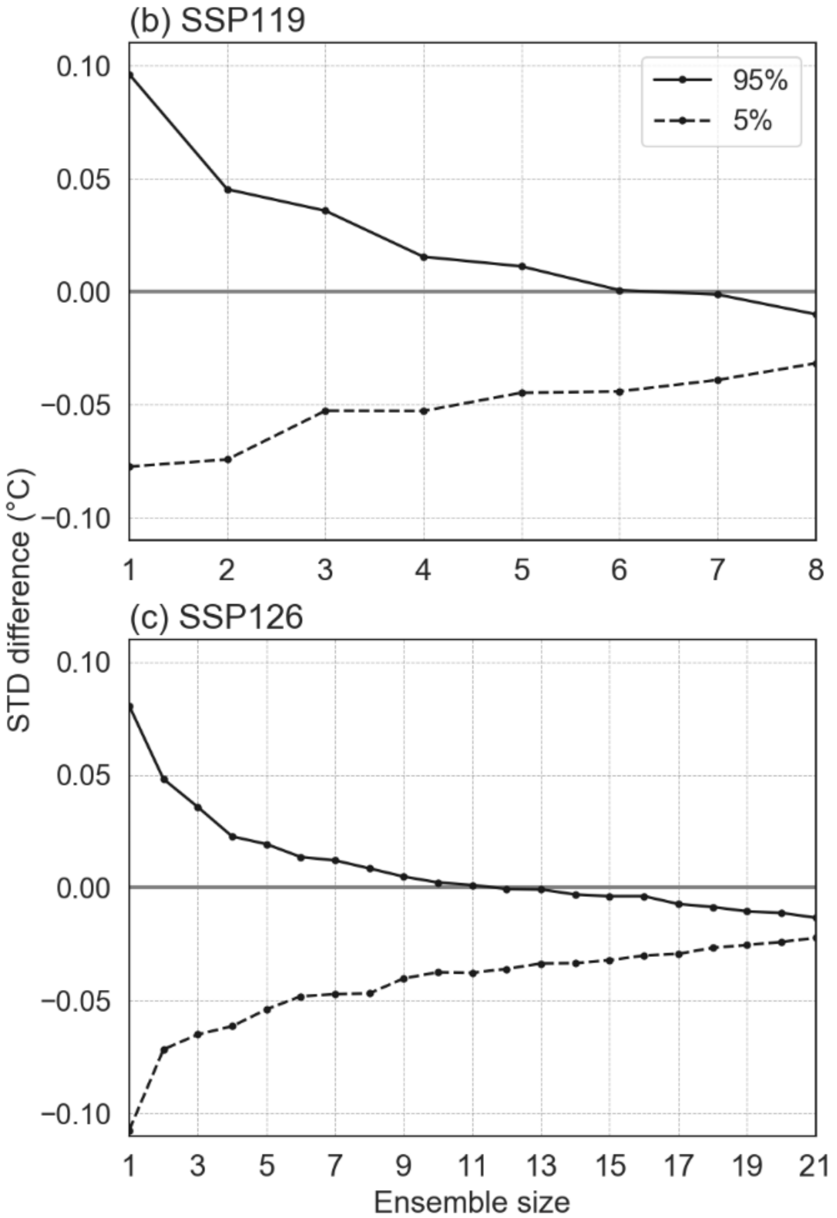
Chen, Shi et al. 2021, GRL

NPO



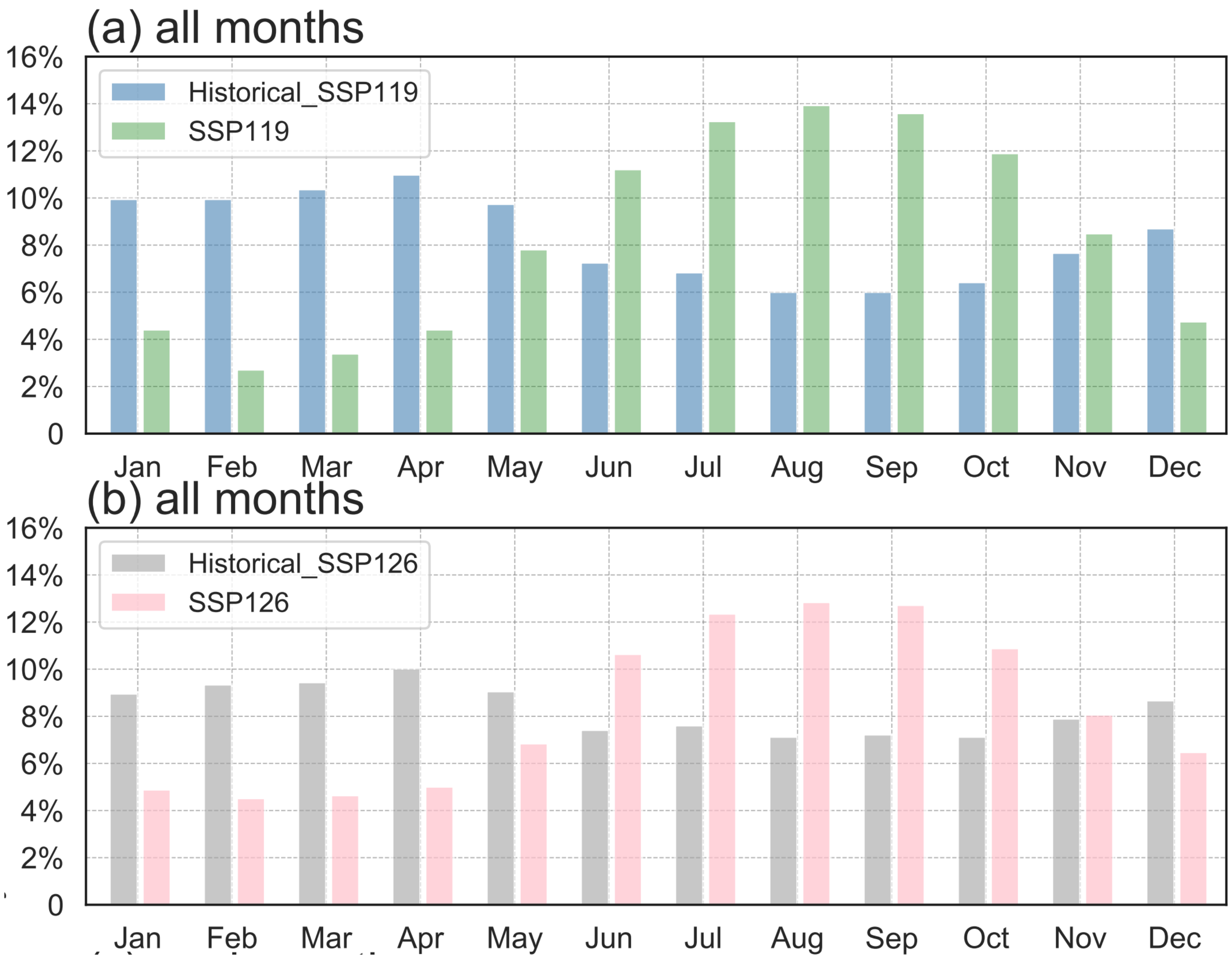
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
2019-2020 case
2015 case
2013-2014 case
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Month

The minimum number of models

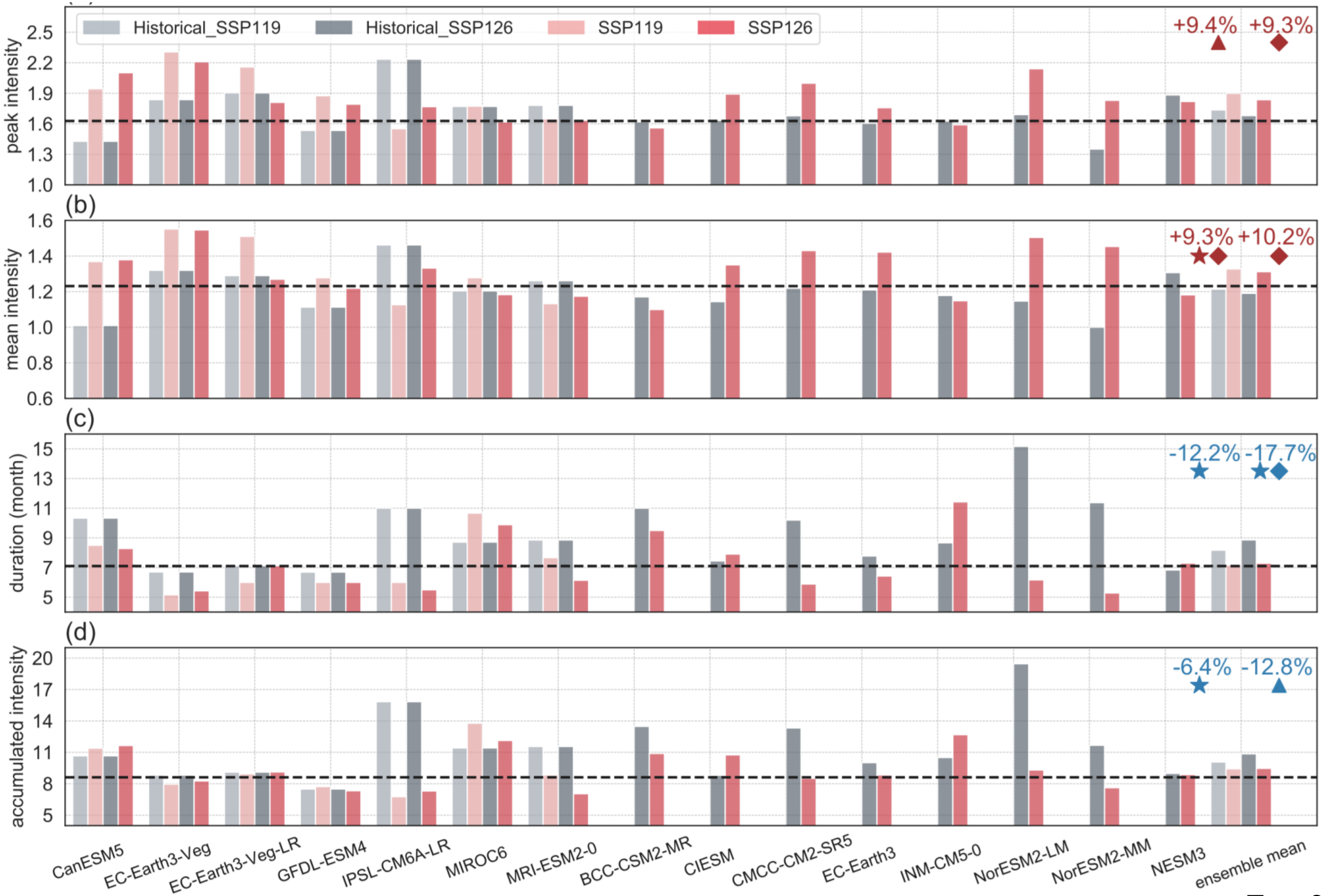


- The minimum ensemble size is determined when the 5% and 95% percentiles are in the same sign.
- By this definition, the minimum ensemble sizes are 7 SSP119 models (Fig. 1b) and 12 SSP126 models (Fig. 1c), both of which are within the numbers of the corresponding selected models.

Timing shift: ALL months included

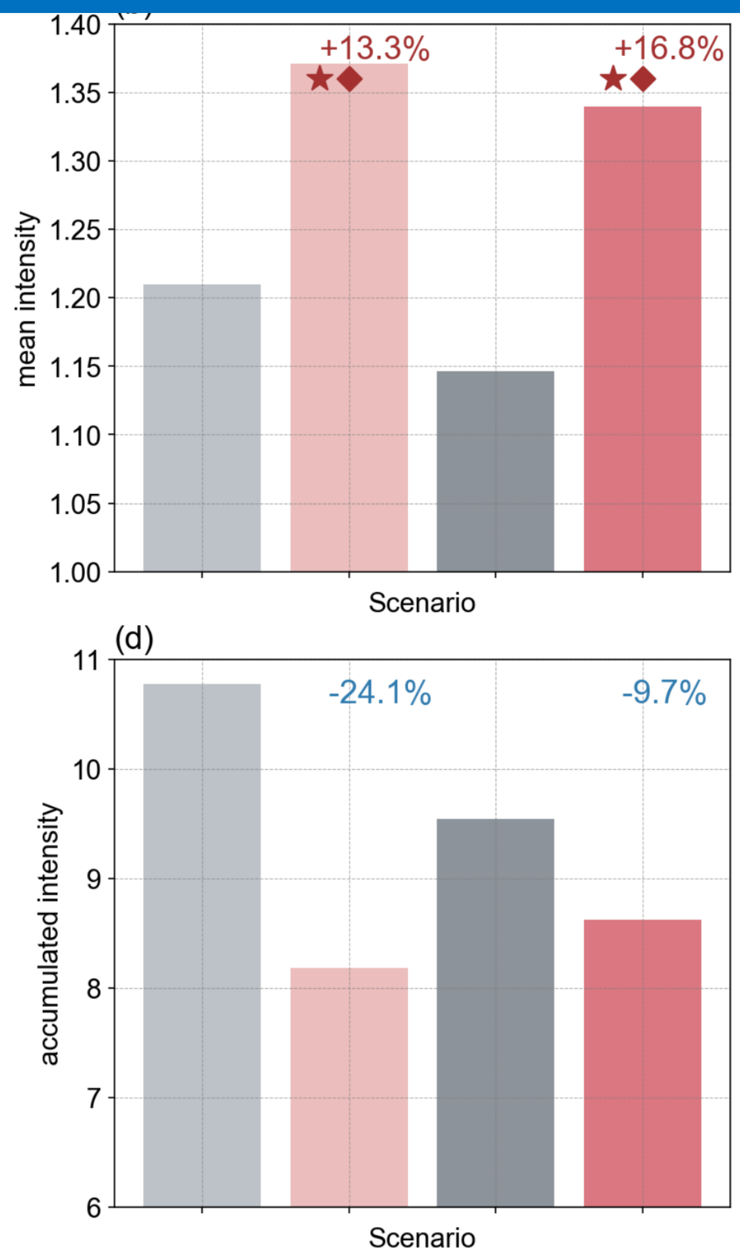


Warm blobs cases in all seasons

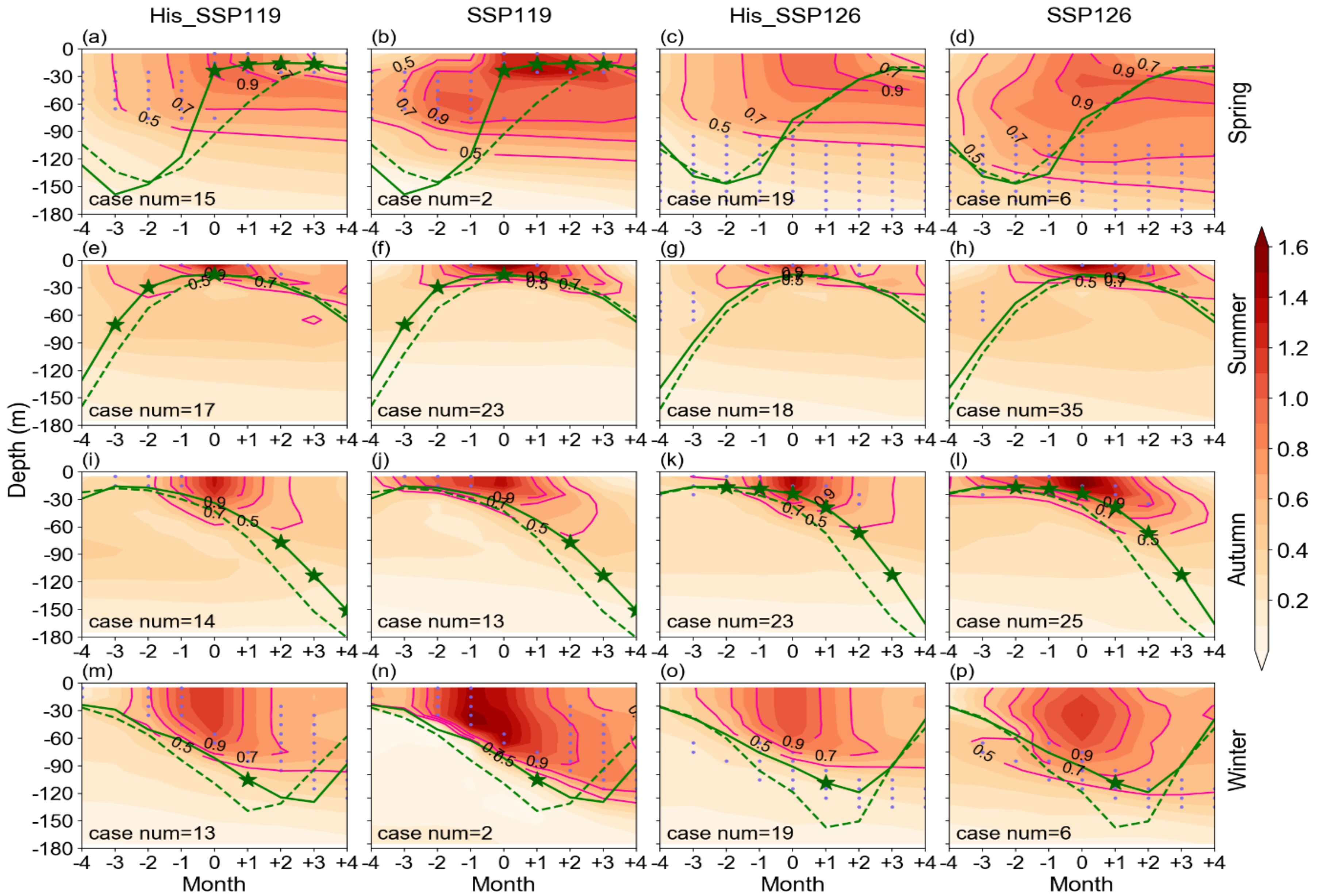


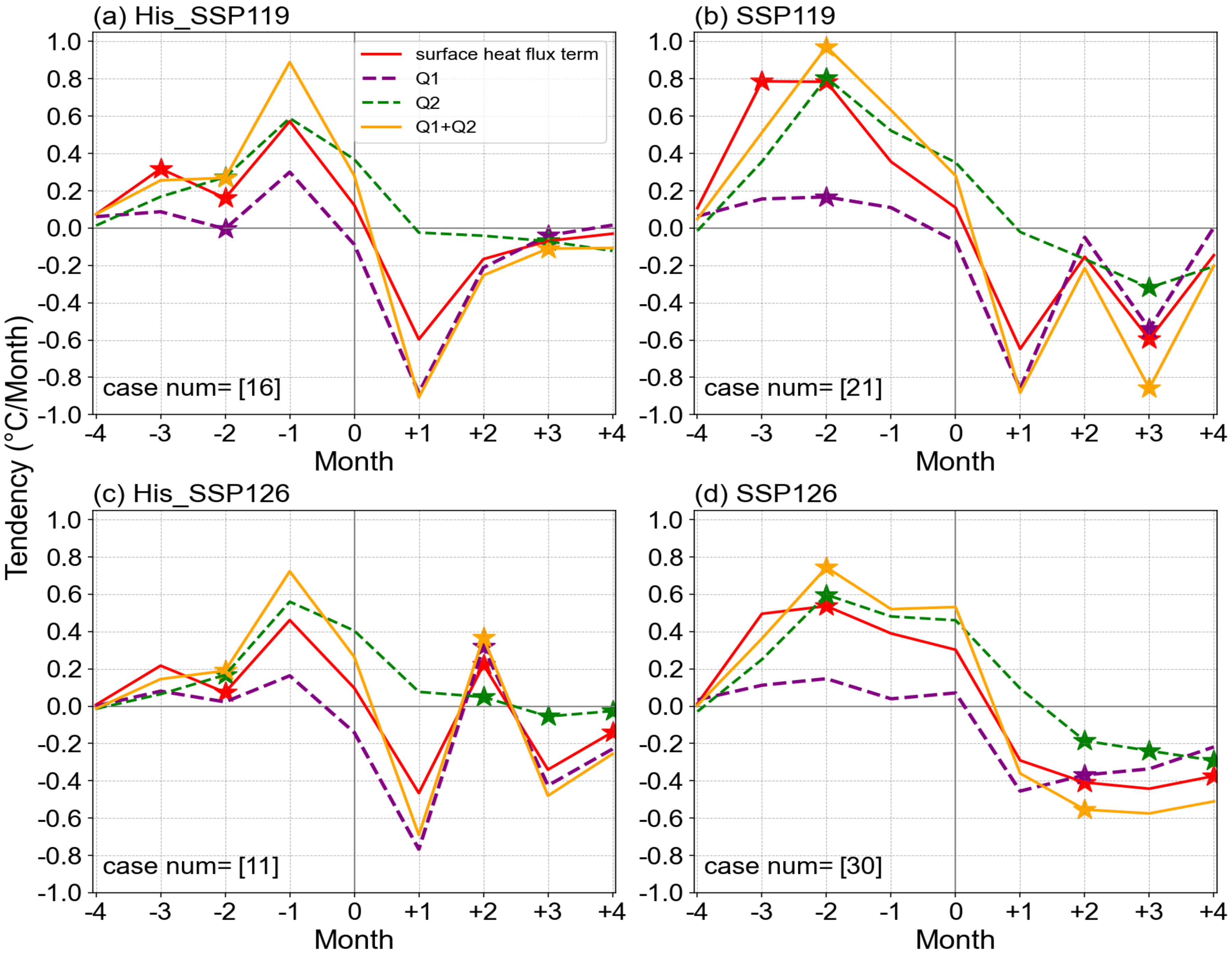
Tang, Shi, et al. 2022, JC, minor revision

Property changes



Vertical temperature anomalies in all seasons





$$\left(\frac{Q}{h}\right)' \approx \frac{Q'}{\bar{h}} - \frac{\bar{Q}h'}{\bar{h}^2} - \left(\frac{Q'h' - \overline{Q'h'}}{\bar{h}^2}\right)$$

Contribution of heat flux and mixed layer depth

$$\rho C_p \frac{\partial}{\partial t} T = \frac{Q_0}{h} - \rho C_p \left[u \cdot \nabla T + \left(w_h + \frac{dh}{dt} \right) \frac{(T - T_h)}{h} + \frac{k}{h} \frac{\partial T}{\partial z} \bigg|_{z=h} \right]$$

temperature tendency = surface heat flux + horizontal advection + vertical entrainment + diffusion

(Cronin et al. 2015; Schmeisser et al. 2019)

first-order Taylor expansion

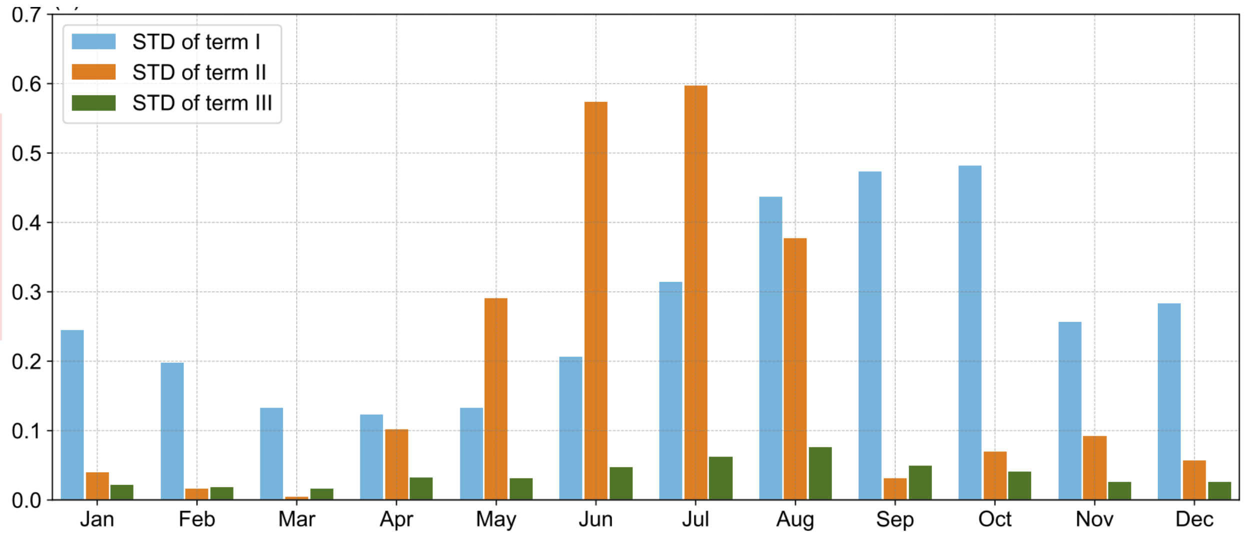
Alexander and Penland (1996)
Amaya et al. (2020, 2021)

$$\left(\frac{Q}{h}\right)' \approx \underbrace{\frac{Q'}{\overline{h}}}_{\text{I}} - \underbrace{\frac{\overline{Q}h'}{\overline{h}^2}}_{\text{II}} - \underbrace{\left(\frac{Q'h' - \overline{Q'h'}}{\overline{h}^2}\right)}_{\text{III}}$$

Term I: contribution of Q'

Term II: contribution of mixed layer depth anomalies h'

Term III: nonlinear interaction between Q' and h'



- Term I: much larger from September to March
- Term II: much larger from May to July

Shi et al. 2022, GRL

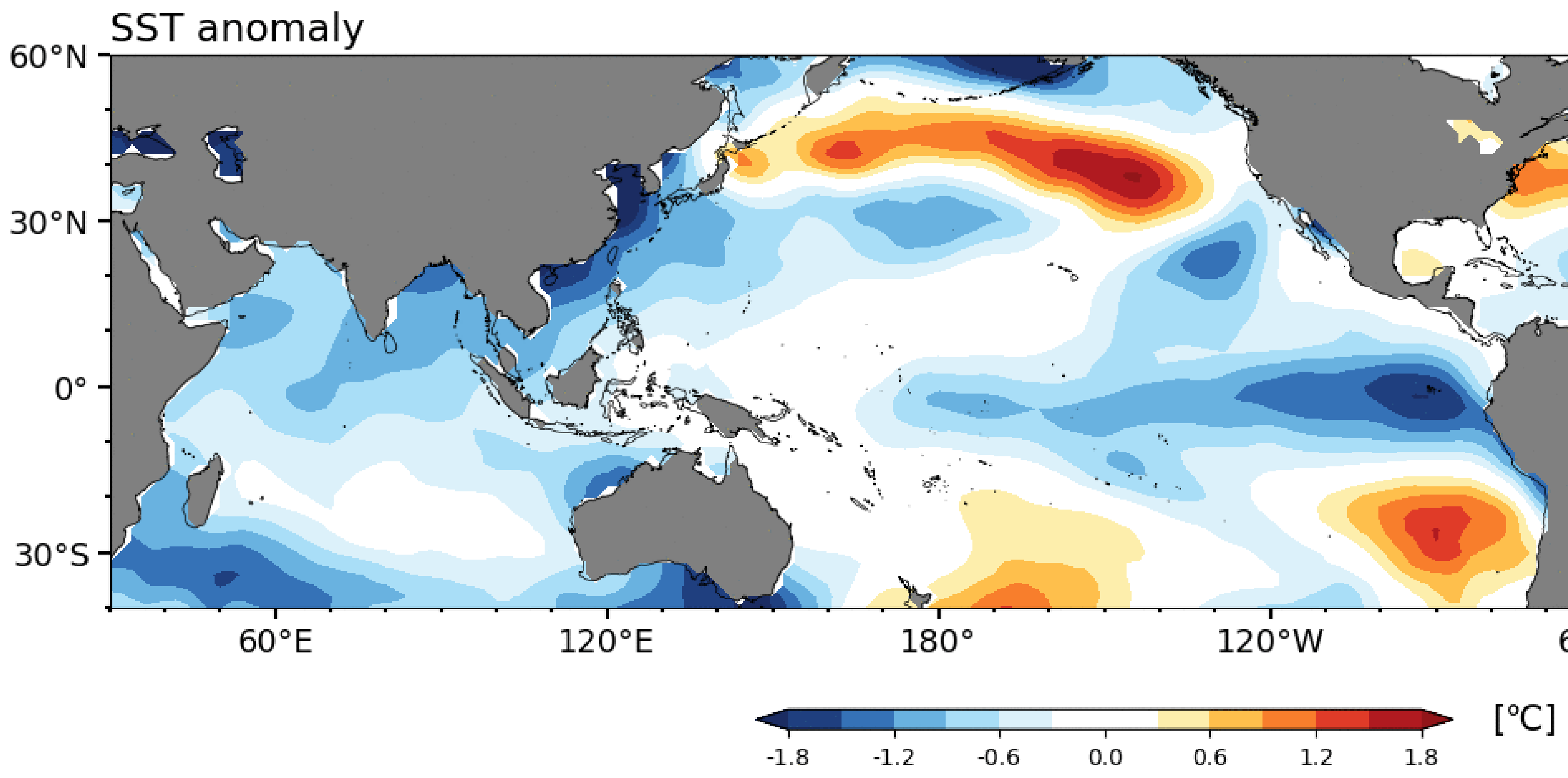
Linkage with ENSO

Probability of El Niño events in the following winter after the summer peak of warm blobs. "*" and "***" indicate the difference exceeding the 0.1 and 0.01 significance levels based on student's *t* test.

El Niño	Historical_SSP119	SSP119	Historical_SSP126	SSP126
>1.5°C	0.0%***	26.1%***	10.7%	20.7%
>1.0°C	11.8%*	34.8%*	21.4%	36.2%
>0.5°C	29.4%	52.2%	39.3%	48.3%

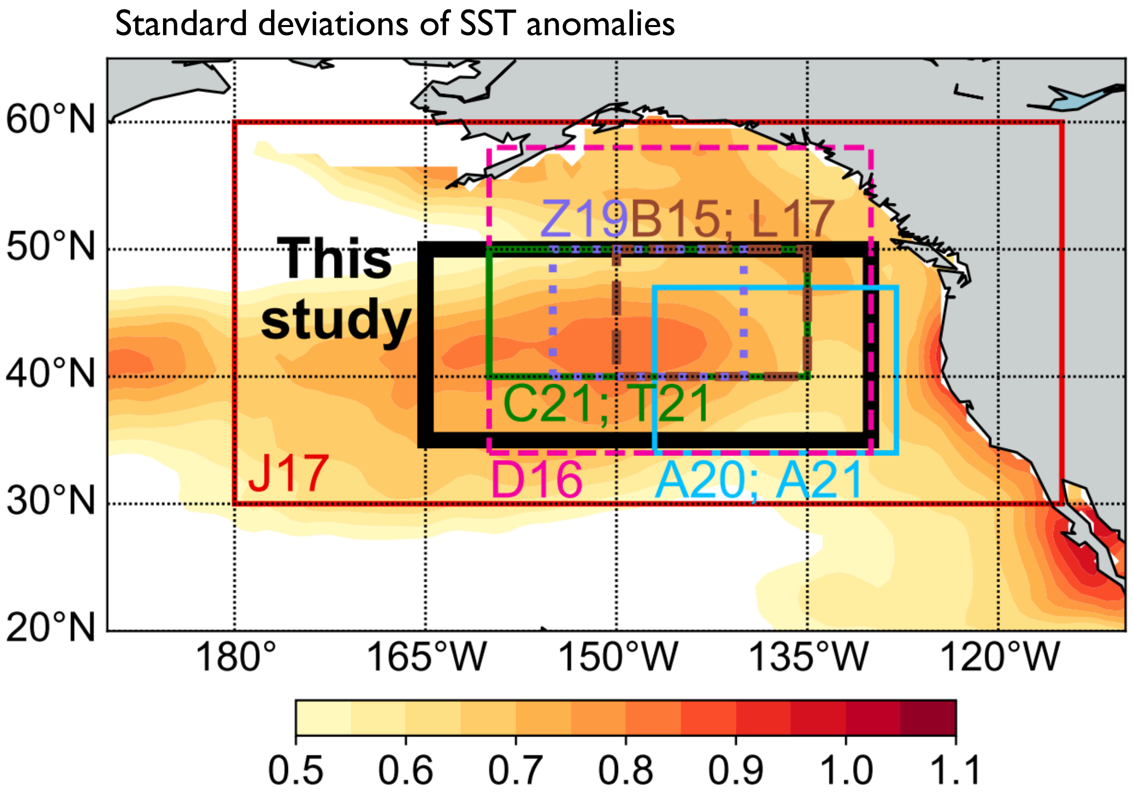
Tang, Shi, et al. 2022, JC, minor revision

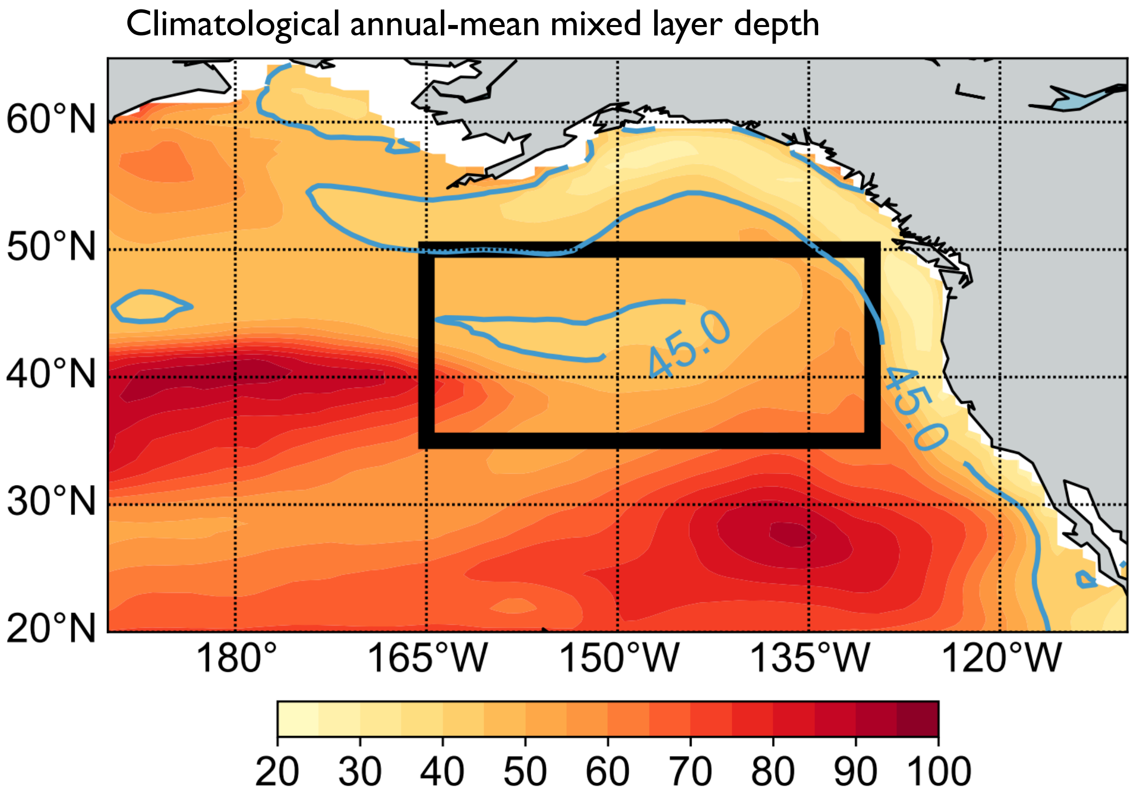
Focusing on the location of warm blobs



Credit to Hao Huang

Location of warm blobs and mixed layer depth

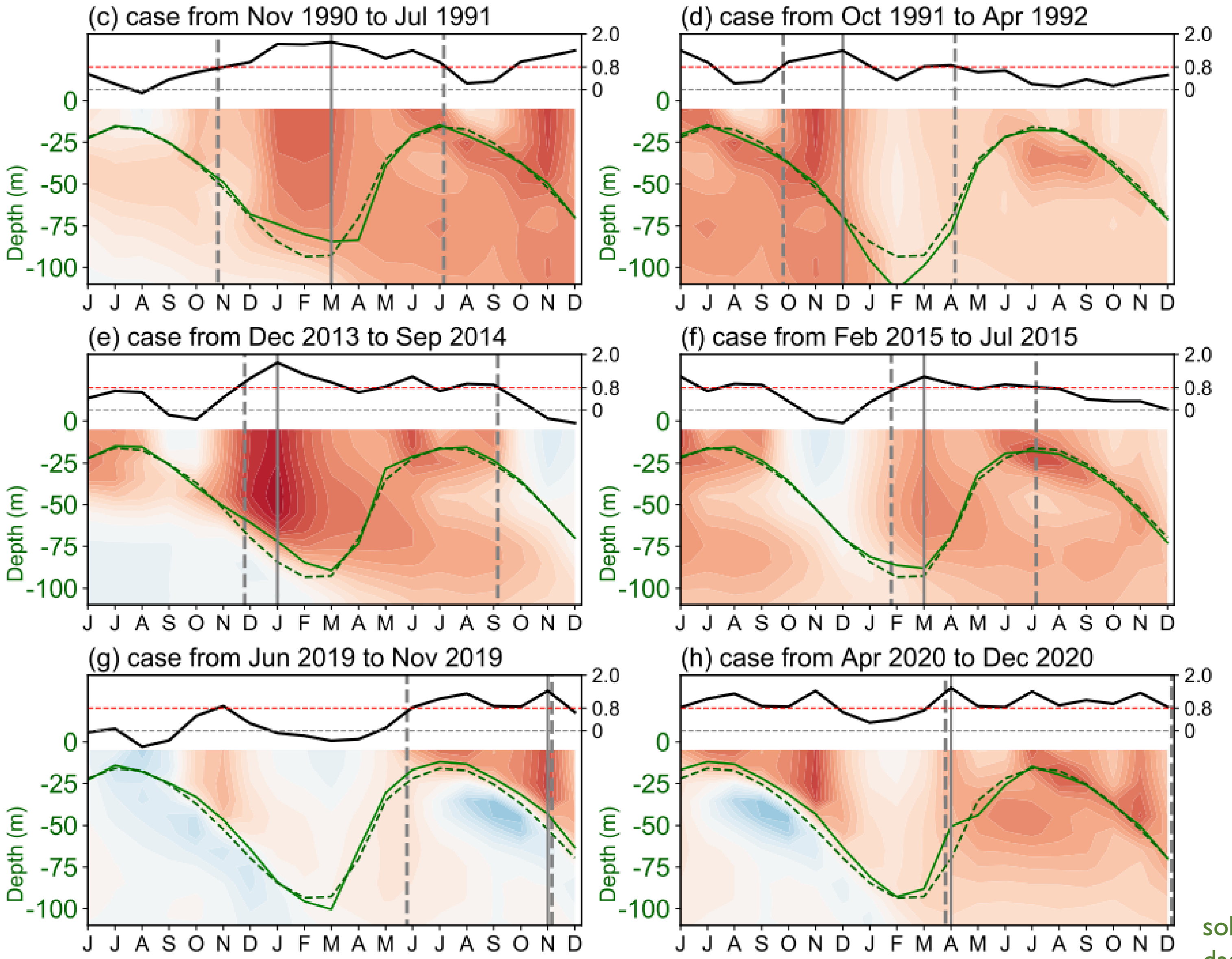




- Northeast Pacific warm blobs appear more frequently in areas with a shallow mixed layer
- We unify and re-define a larger region of **165°–130°W and 35°–50°N** to study warm blobs

Shi et al. 2022, GRL

Vertical extent of warm blobs with mixed layer depth



- **winter, spring, autumn**

Warm anomalies are mostly confined to mixed layers

- **summer**

Large portion of warm waters can be stored beneath mixed layer due to its shoaling

- **Mixed layer depth**

• usually becomes shallower
• may be related to the weaker wind speed and mixing in the upper ocean (Amaya et al. 2020; Bond et al. 2015)

solid line: actual MLD
dashed line: climatological MLD

Shi et al. 2022, GRL