ICRC-CORDEX 2023

Session A1: Earth System Modelling in the regional context

Regional climate simulation of the record-breaking heavy rainfall over East Asia in 2020: model evaluation and impact of global warming

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※ This work was supported by Korea Environment Industry &Technology Institute (KEITI) through "Climate Change R&D Project for New Climate Regime.", funded by Korea Ministry of Environment (MOE) (1485018907).
We thank the supercomputing resources of the UNIST Supercomputing Center.

Introduction

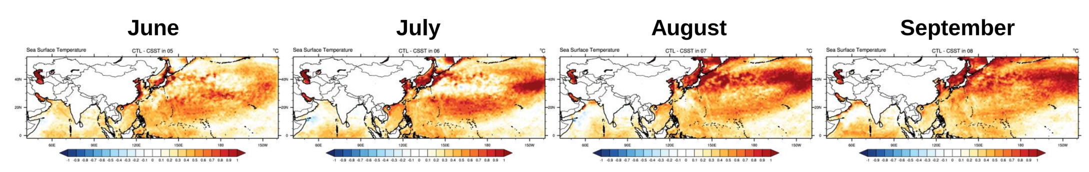
- In the summer of 2020, we experienced an even more extreme East Asian summer monsoon (EASM) that caused significant damages to countries in East Asia, breaking the records set in 1998
- There was a noticeable positive [negative] anomaly in precipitation over EASM [western North Pacific summer monsoon (WNPSM)] in 2020 summer, compared to that of the climatology
- The influences of various longterm variabilities were analyzed well in other studies, however, despite the clear trend of increasing SST in the western North Pacific, it has not been explored whether the intense EASM activity in 2020 was affected by the rising SST caused by global warming
- Therefore, this study investigated the impact of increased SST due to global warming on the record-breaking EASM in 2020 by using regional climate model

Data and Method

Data

Sea Surface Temperature (SST)	ERSST (NOAA Extended Reconstructed Sea Surface Temperatures Version 5 monthly 2°x2°) HadISST (Hadley Centre Sea Ice and Sea Surface Temperature data set monthly 1°x1°)
Reanalysis	ERA5 (ECMWF Reanalysis v5 6hourly and monthly 0.25°x0.25°)
Precipitation	GPCP (Global Precipitation Climatology Project V3.2 monthly 0.5°x 0.5°) IMERG (Integrated Multi-satellitE Retrievals for GPM V06 0.1°× 0.1°)

Difference between prescribed SST in CTL and CSST



Figures are showing the model domain as well

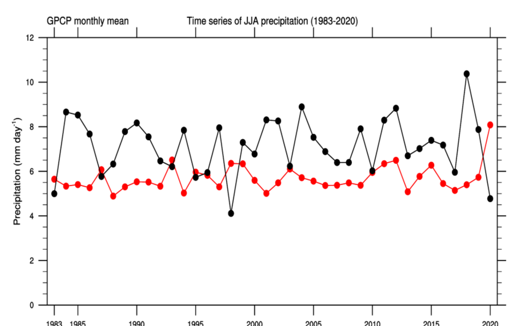
Model Configurations

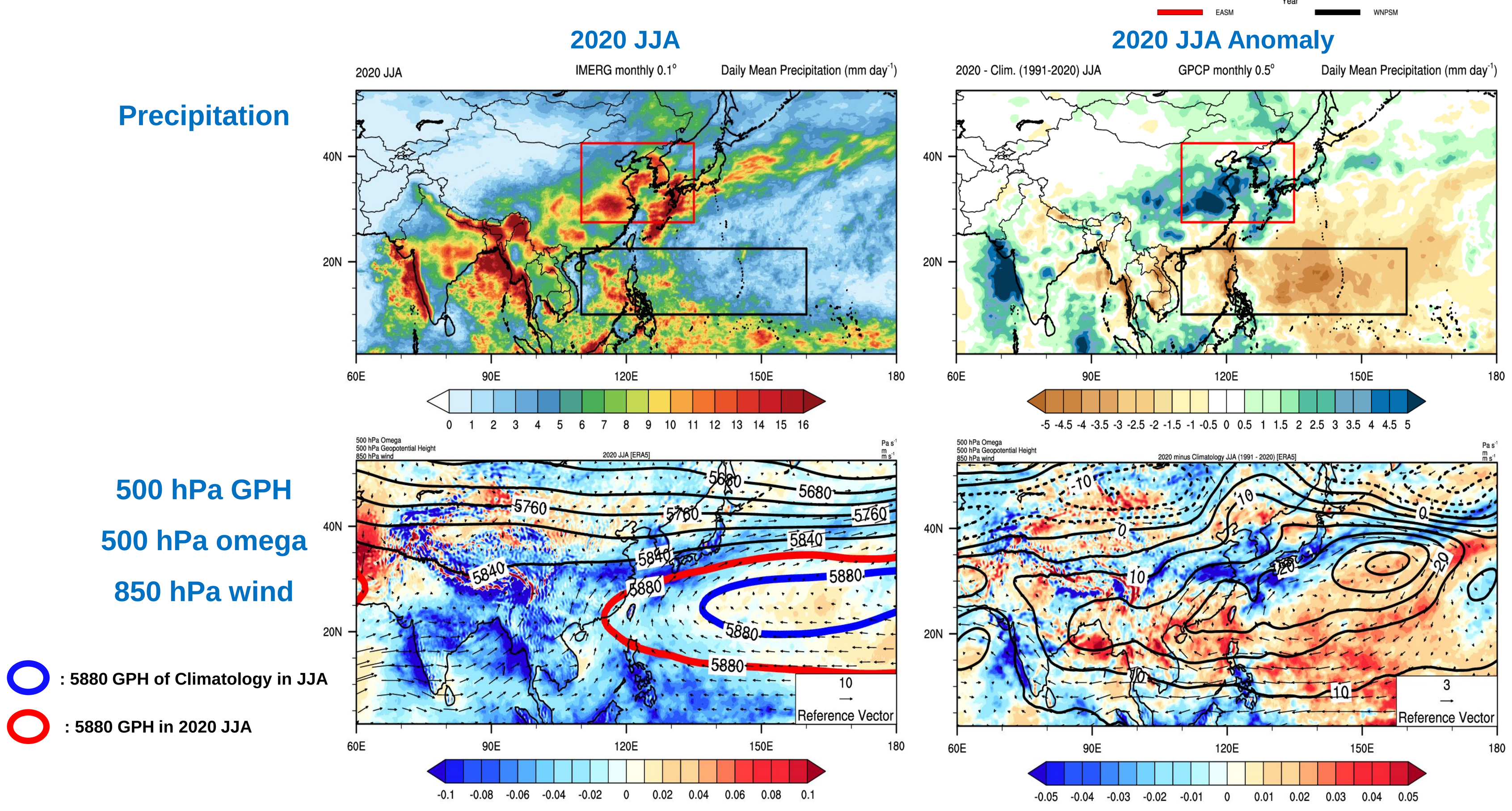
Model	Weather Research and Forecast (WRF) Model V4.1.3
Control experiments (CTL)	Original ERA5 SST
Cool SST experiments (CSST)	Original ERA5 SST minus 22 × slopes of ERA5 SST monthly trend line
Simulation period	2020-05-01, 00 UTC to 2020-09-01, 00 UTC 2020-05-01, 12 UTC to 2020-09-01, 00 UTC 2020-05-02, 00 UTC to 2020-09-01, 00 UTC 2020-05-02, 12 UTC to 2020-09-01, 00 UTC 2020-05-03, 00 UTC to 2020-09-01, 00 UTC
Analysis period	2020-05-31, 15 UTC to 2020-08-31, 15 UTC
Horizontal grids (resolution)	1441 × 571 (12 km)
Vertical grids (model top)	35 levels (50 hPa)
Initial/boundary condition	ECMWF Reanalysis V5 (ERA5) data, six hourly, 0.25˚ horizontal resolution
Microphysics parameterization	WSM6 (Hong and Lim 2006)
Cumulus parameterization	KSAS (Kwon and Hong 2017)
Radiation-shortwave	RRTMG (Iacono et al., 2008)
Radiation-longwave	RRTMG (Iacono et al., 2008)
Planetary boundary layer	YSU (Hong et al., 2006)
Land surface model	Noah Land Surface Model (Tewari et al., 2004)

Results

The characteristics of 2020 EASM

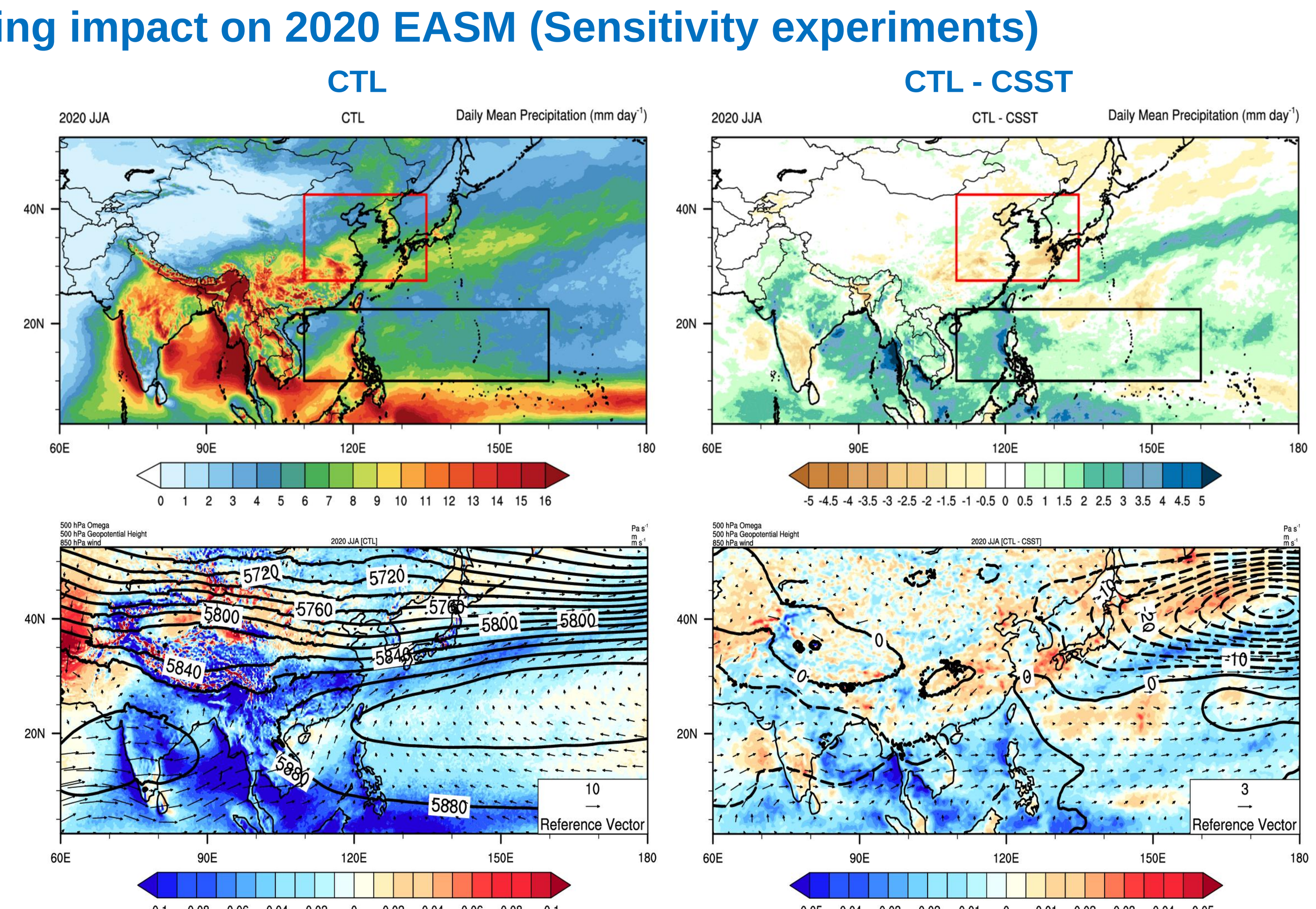
Time series of precipitation in JJA





- There was a noticeable positive anomaly in precipitation over EASM in 2020 summer and negative anomaly in WNPSM region, compared to the climatology
- Synoptic patterns also revealed significant difference in 2020, including the northwestward expansion of the western North Pacific subtropical high (WNPSH), reduced westerly winds between the IO and the WNP, and weakened local Hadley circulation

Global warming impact on 2020 EASM (Sensitivity experiments)



Daily mean and difference of precipitation by area

	OBS		CTL		CTL - CSST	
Region	EASM	WNPSM	EASM	WNPSM	EASM	WNPSM
Mean Precipitation	8.72	5.27	6.65	6.16	-0.32 (-4.8%)	+1.17 (+19.0%)

unit : mm/day

Control experiment

- The control experiment successfully simulated the spatial distribution of rainfall and synoptic patterns compared to the reanalysis data for the summer of 2020, including EASM, and the WNPSM region

Precipitation

- Precipitation differences in low-latitude regions, including the WNPSM, are proportional to SST differences
- In EASM, precipitation is decreased despite of the increased SST
- The precipitation difference (CTL - CSST), that is, the effect of SST warming on precipitation, shows a spatial distribution opposite to the anomaly of precipitation in 2020

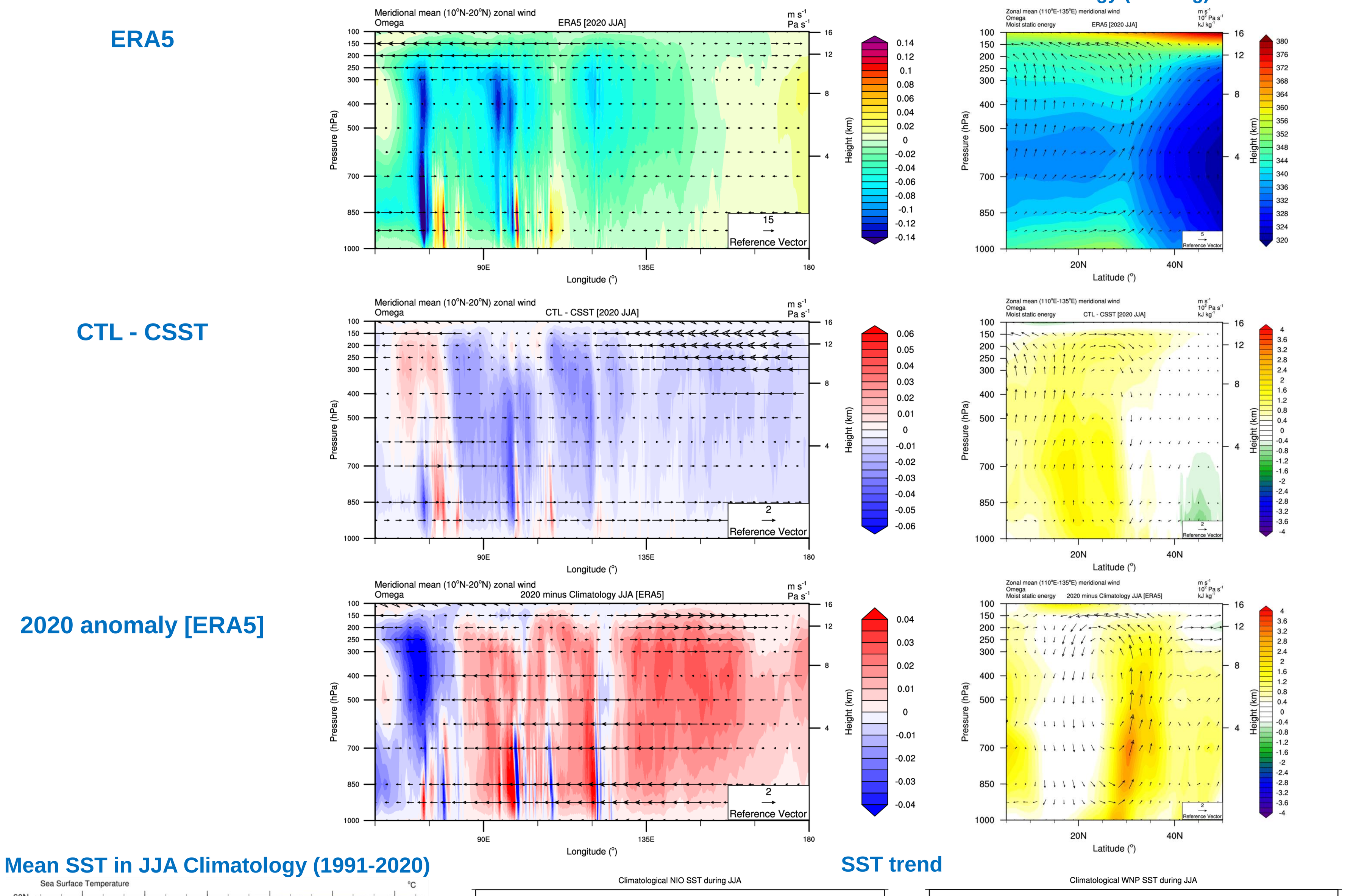
Synoptic pattern

- CTL – CSST : WNPSH is relatively contracted, updrafts & westerlies are strengthened in low latitudes
  anticyclonic circulation and updrafts are weakened in East Asia
- The difference of synoptic field (CTL - CSST) and that of the anomaly in 2020 shows the opposite spatial distribution
- SST warming suppresses formation of anomalous synoptic field in 2020

The characteristics of 2020 EASM

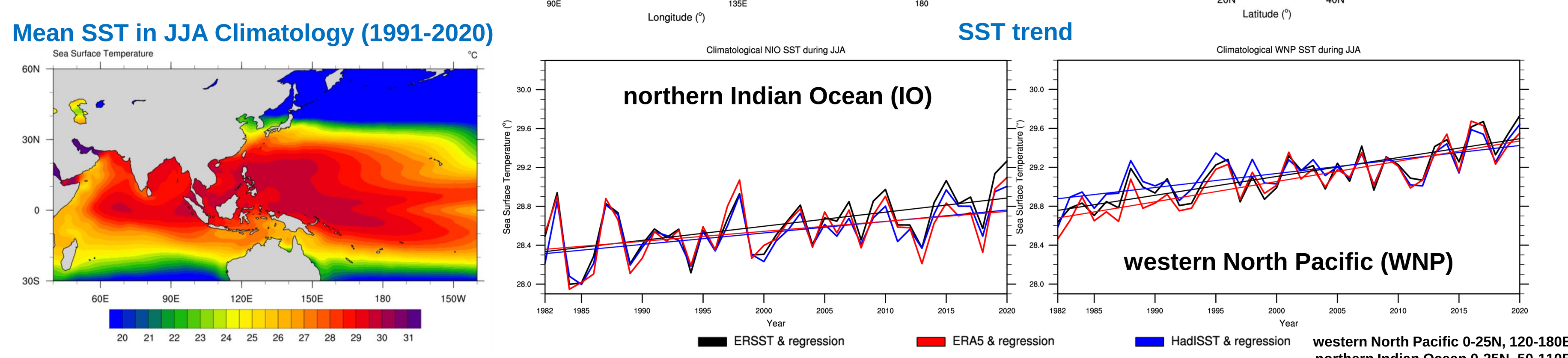
Meridional mean (10°N-20°N) zonal wind
Omega (shading)

Zonal mean (110°N-135°N) meridional wind
Omega
Moist static energy (shading)



Mean SST in JJA Climatology (1991-2020)

SST trend



Moist Static Energy (MSE) : $S = L_v \cdot q + C_p \cdot T + g \cdot z$

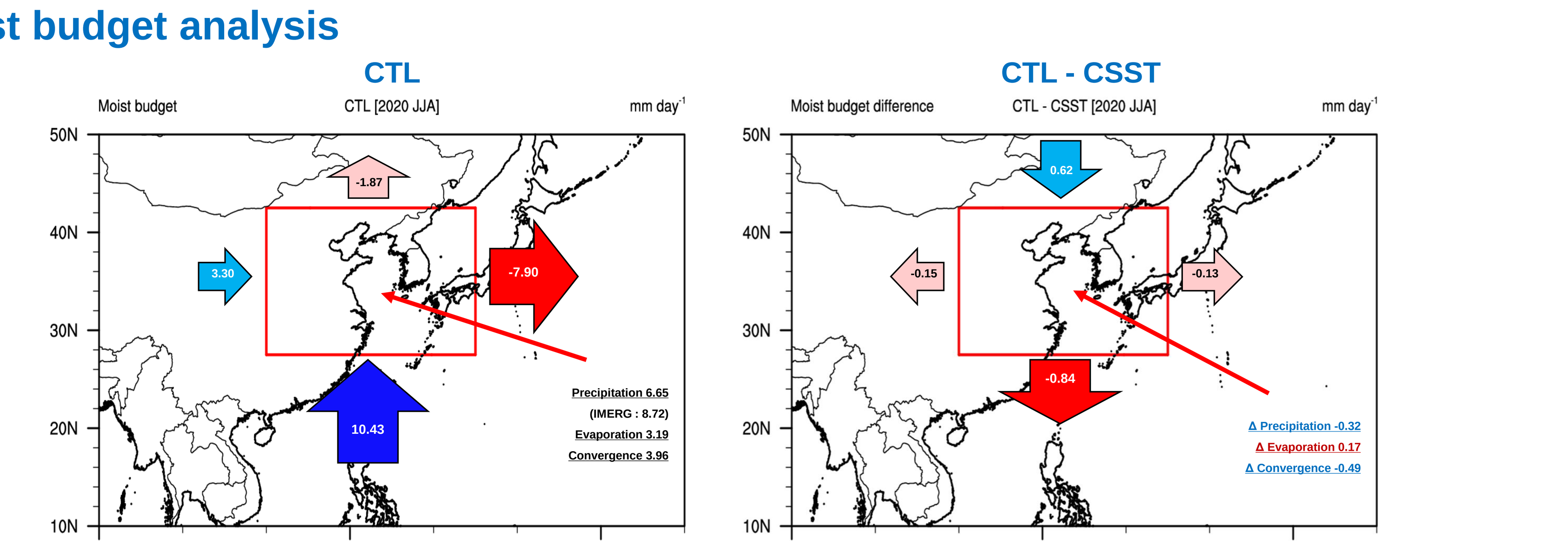
Zonal wind and omega

- CTL – CSST :The SST and SST increase of the WNP is higher than the IO
- SST gradient increases → low-level westerly wind ↑ → Walker circulation ↑ → Hadley circulation ↑
- The difference of circulation (CTL – CSST) shows the opposite spatial distribution of the 2020 circulation field anomaly
- SST warming suppresses formation of anomalous circulation field in 2020

Meridional wind and moist static energy

- CTL – CSST : MSE and updraft increase in low latitudes, downdraft increase in mid-latitudes
- Low-latitude SST ↑ → updraft ↑ → Hadley circulation ↑ → low-latitude updraft ↑ and mid-latitude updraft ↓ → mid-latitude precipitation ↓
- The difference of circulation (CTL – CSST) shows the opposite spatial distribution of the 2020 circulation field anomaly
- SST warming suppresses formation of anomalous circulation field in 2020

Moist budget analysis



$$\frac{1}{g}\int_0^1 \frac{\partial p^* q}{\partial t} d\sigma = -\frac{1}{g}\int_0^1 \nabla\cdot(p^* q \mathbf{V}) d\sigma + E - P + D$$

① ②

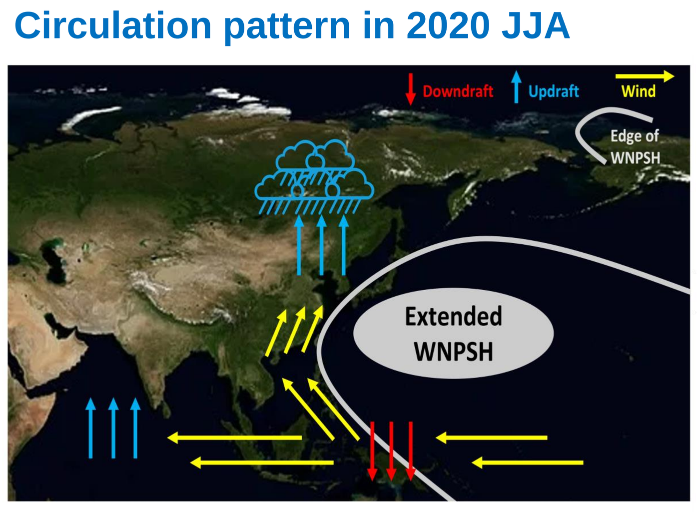
① : moisture storage in the column　E : Evaporation　D : Diffusion

② : moisture convergence　P : Precipitation

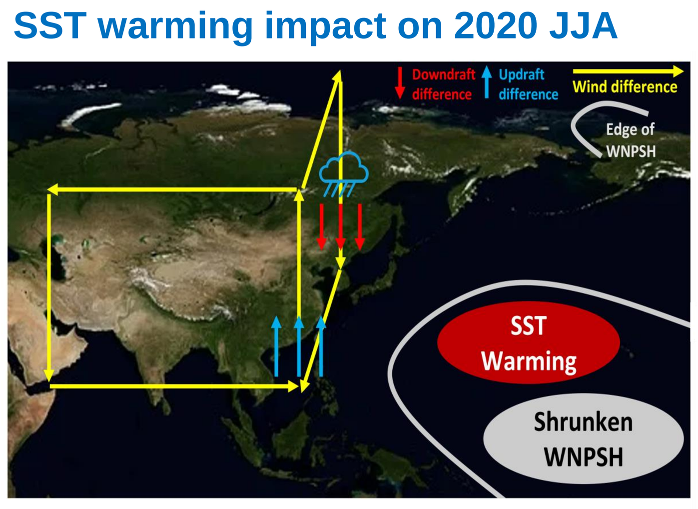
- The convergence is derived by the net of the moisture transported through each boundary
- CTL – CSST (Global warming impact) :
  Increase in evaporation (thermodynamic) & Decrease in convergence (dynamic)
- | Convergence | >> | Evaporation | in 2020
- but global warming may lead to | Convergence | << | Evaporation |

Summary

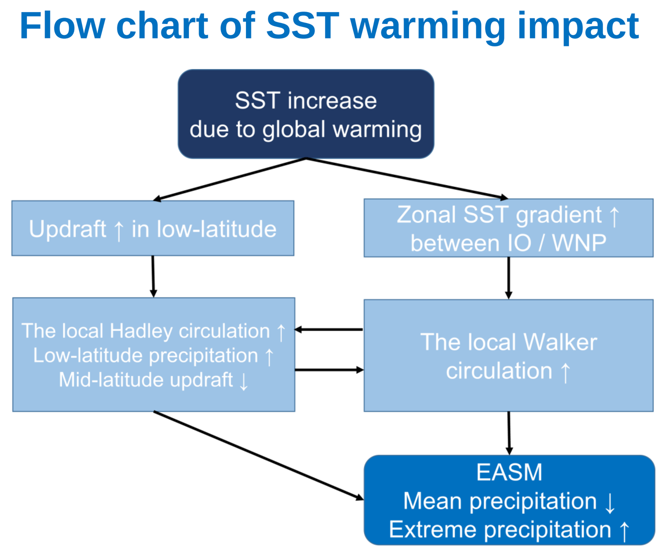
Circulation pattern in 2020 JJA



SST warming impact on 2020 JJA



Flow chart of SST warming impact



- This study investigated the impact of SST increase due to global warming on EASM in 2020
- The increase in SST due to global warming changes the large-scale circulation field dynamically and thermodynamically including the EASM region
- SST increase provides an unfavorable environment for precipitation in East Asia by strengthening the local Walker Circulation and Hadley Circulation
- Overall, the dynamic contribution of the SST increase is still higher than the thermodynamic contribution in EASM region
- Further research will explore whether there is a critical point beyond which the increase in EASM precipitation due to SST increase can not be avoided