# On the role of Indian Ocean SST in influencing the differences in atmospheric variability between 2020-2021 and 2021-2022 La Niña boreal winters

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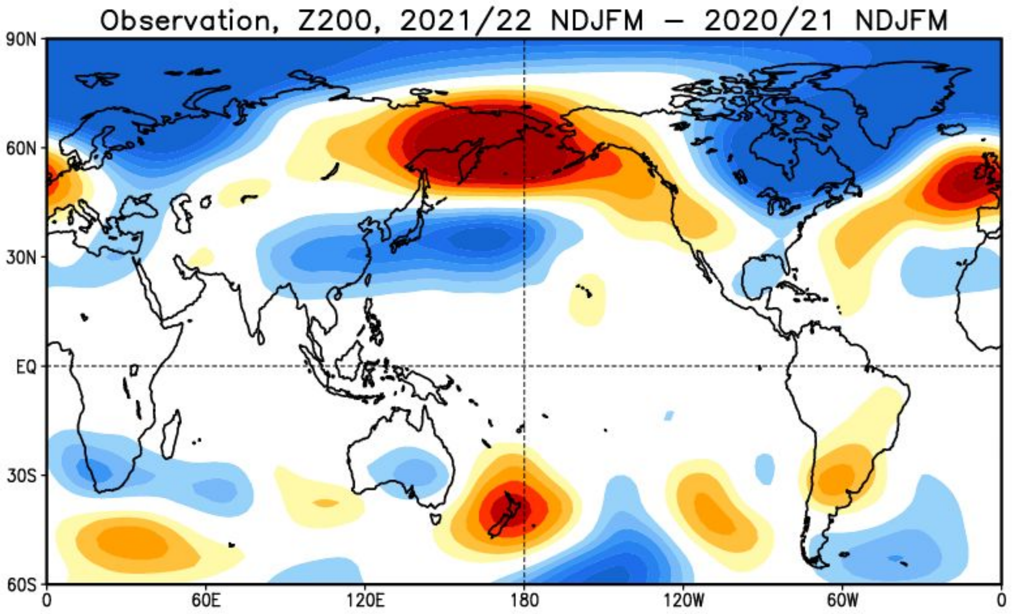
**48th Annual Climate Diagnostics and Prediction Workshop**
**21st Annual Climate Prediction Applications Science Workshop**
**Joint Meeting**

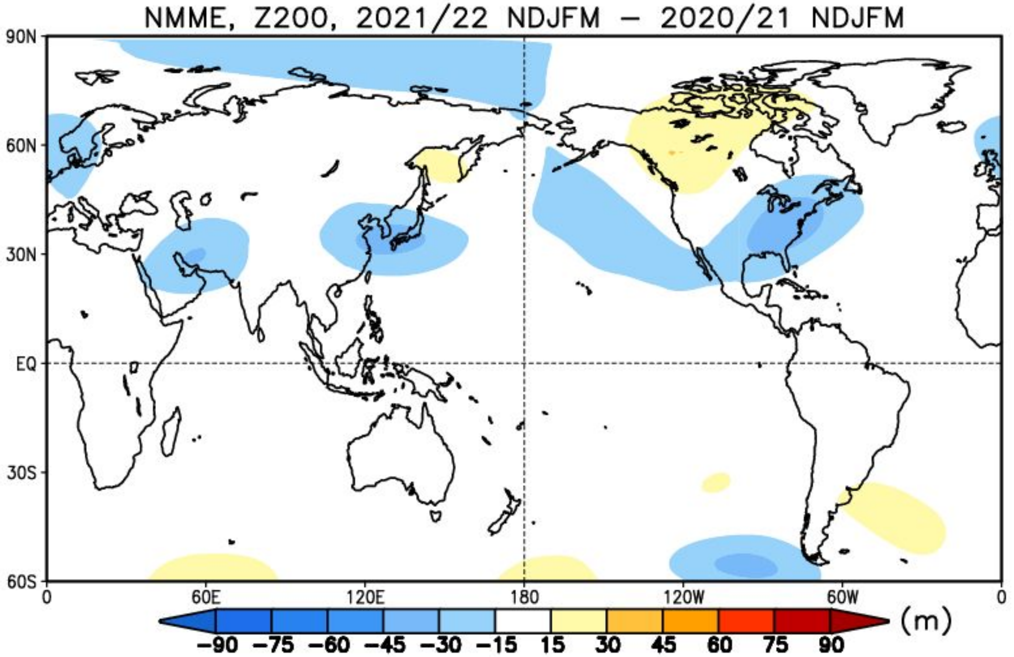
# Z200, 2021/22 NDJFM minus 2020/21 NDJFM

**Observation**




- Observed Z200 difference indicated a tripole pattern consisting of a Japan cyclone, a Bering Sea anticyclone, and a cyclone over North American continent

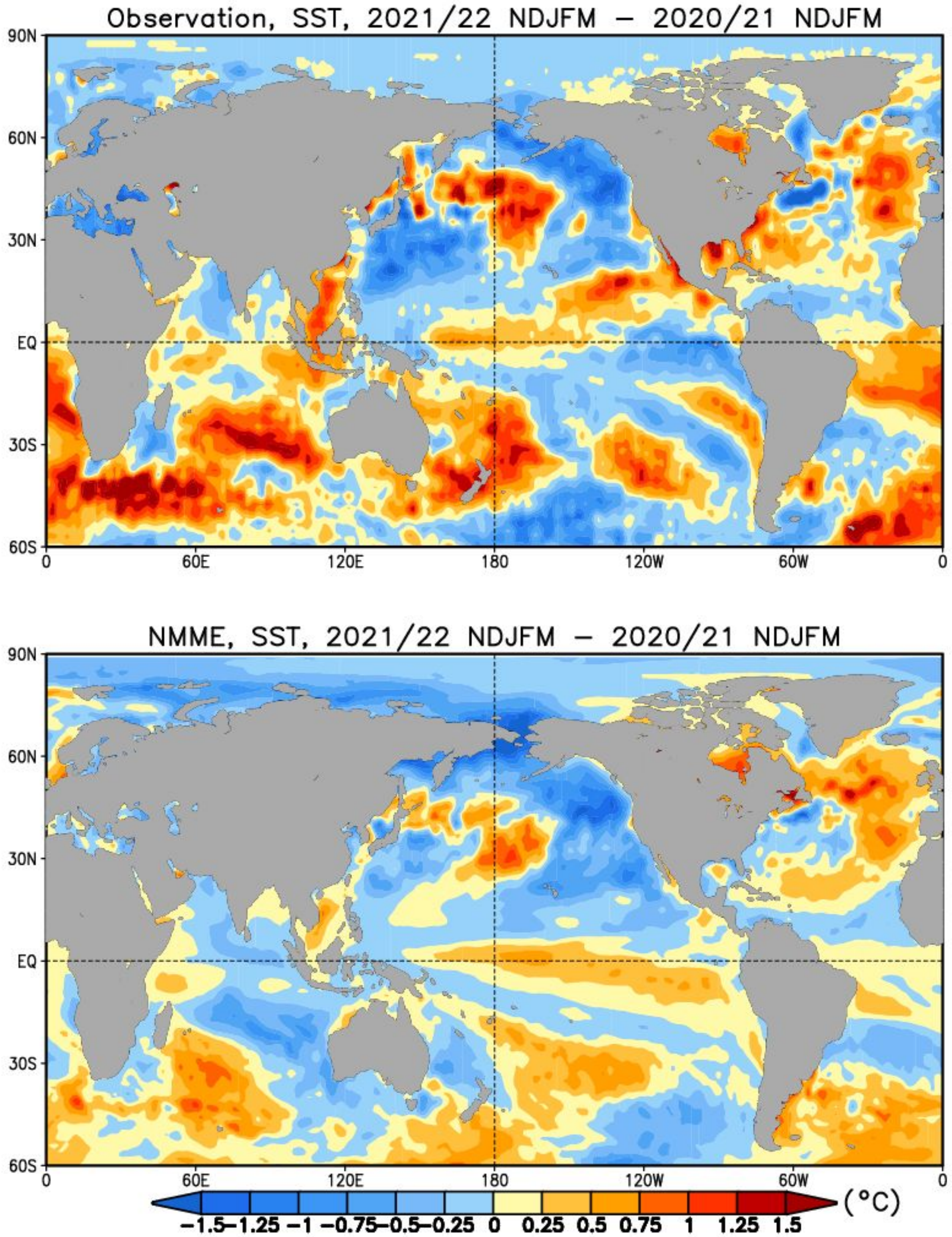
**NMME**




- NMME ensemble mean forecast at 0–month lead failed to predict this feature, and indicated an opposite pattern.

# SST, 2021/22 NDJFM minus 2020/21 NDJFM

**Observation**




- warmer over central North Pacific, North Atlantic, Indian Ocean and equatorial central Pacific

- colder over equatorial eastern Pacific

**NMME**

- NMME 0–month lead predicted SST difference was colder over eastern Indian Ocean and maritime continent than observation.

# Research Questions

(1) What is the role of atmospheric internal variability in influencing the observed circulation difference between two La Nina winters?

(2) What are the relative contributions of SST from different ocean basins to the differences in observed heights?

(3) What was the impact of errors in prediction of SST in NMME forecasts?

# Data and Model Simulations

- **Observational data**

NOAA Optimal Interpolation (OI) SST version 2 (OISSTv2), GPCP precipitation, 200-hPa geopotential height fields from NCEP-NCAR reanalysis

- **NMME forecasts**

We utilize forecasts at 0-month lead from Nov. 1st ICs that predict the subsequent 5-month average of November-March (NDJFM) for 2021 and 2022 La Niña events.

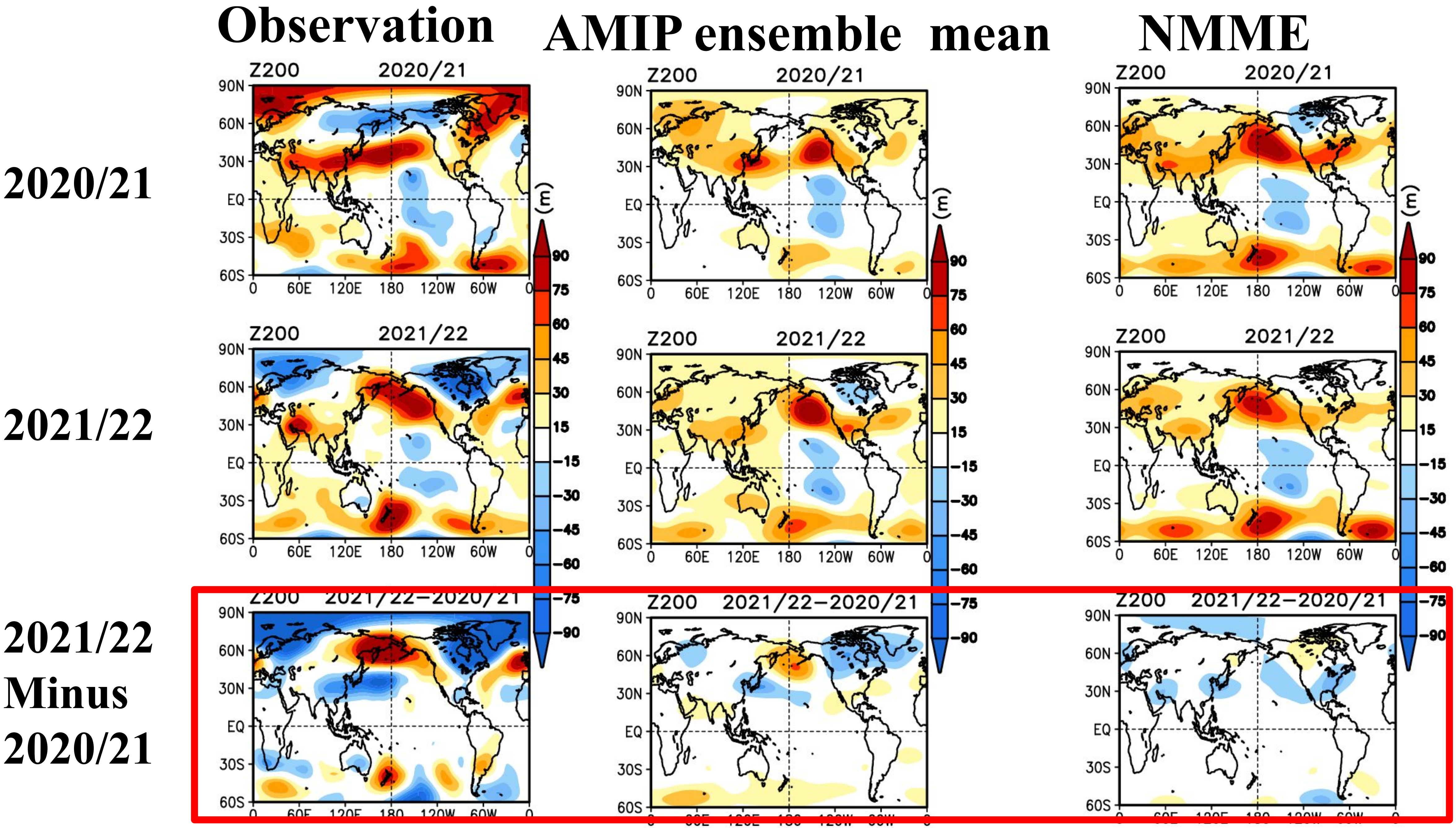
We consider the grand ensemble mean forecasts that include a total of six NMME models.

- **AMIP simulations**

NOAA Climate Prediction Center (CPC) has generated a large 100-member ensemble of AMIP simulations forced with the observed evolution of sea surface temperatures (SSTs) from 1979-Present using the GFSv15 with FV3 dynamical core.

These simulations realistically simulate the observed climate variability and trends, as well as the observed features associated with the atmospheric response to ENSO (Zhang et al. 2024, JGR, revised).

# Z200 anomaly



**(1) What is the role of atmospheric internal variability in influencing the observed circulation difference between two La Nina winters?**

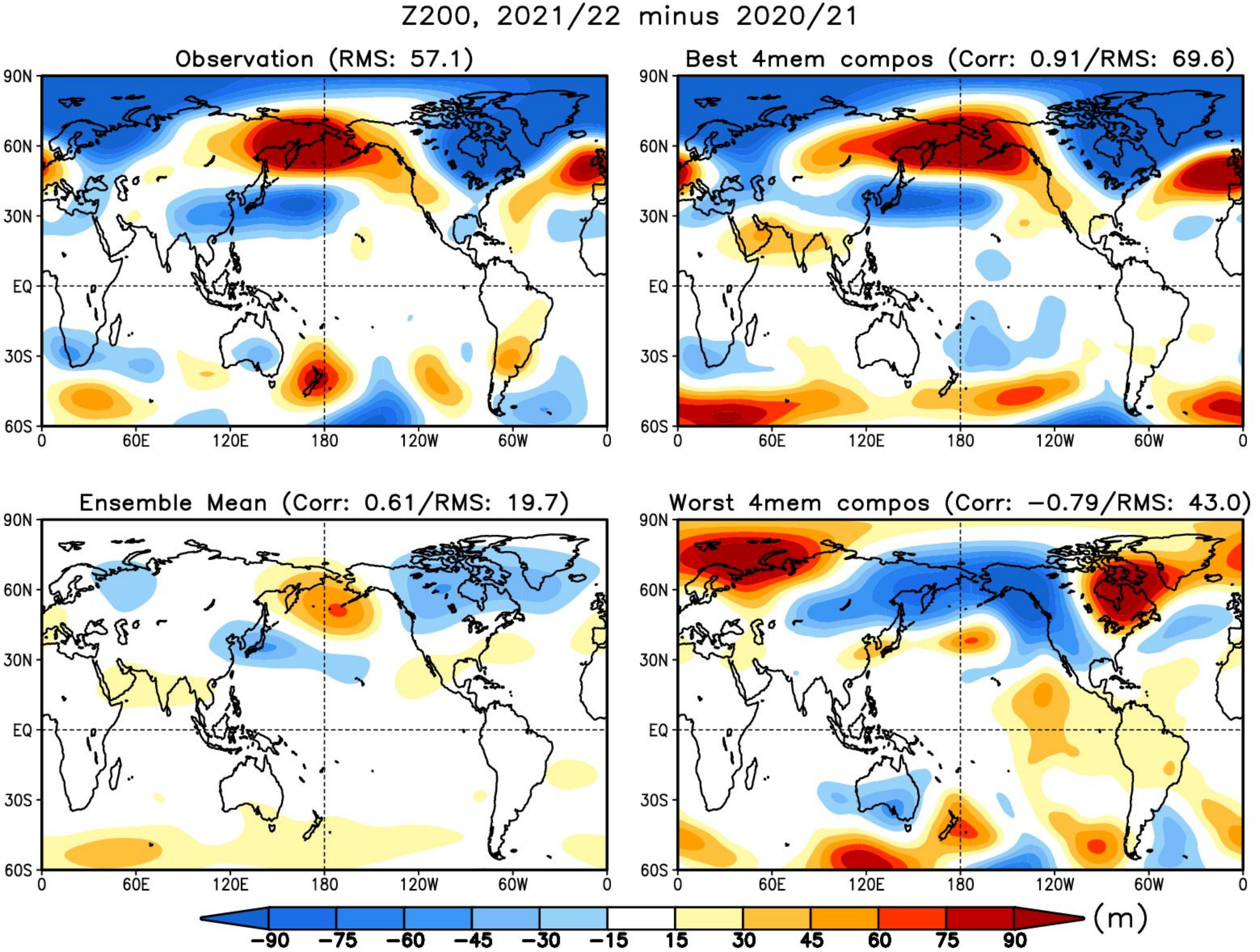
# Z200, 2021/22 minus 2020/21

Observation

Best 4 member Composite

AMIP Ensemble Mean

Worst 4 member Composite



**(2) What are the relative contributions of SST from different ocean basins to the differences in observed heights?**

# Model experiment design

**<u>Control run</u>**

The 1991-2020 climatological mean monthly varying observed SST and SIC

**Perturbed run 1 (global SST run)**

Same as control run, but the observed SST difference between (2021-2022) and (2020-2021) is added to the observed 1991-2020 climatological mean monthly varying fields over the globe. Note that the increment is based on the November-March change, and that same increment is added to November-March of 5- calendar months with a linear tapering in other 7-calendar months.

**Perturbed run 2 (tropical SST run)**

Same as control run, but the observed SST change between Nov2021-Mar2022 and Nov2020-Mar2021 is imposed over the tropics (30S-30N) only.

**Perturbed run 3 (Indian Ocean SST run)**

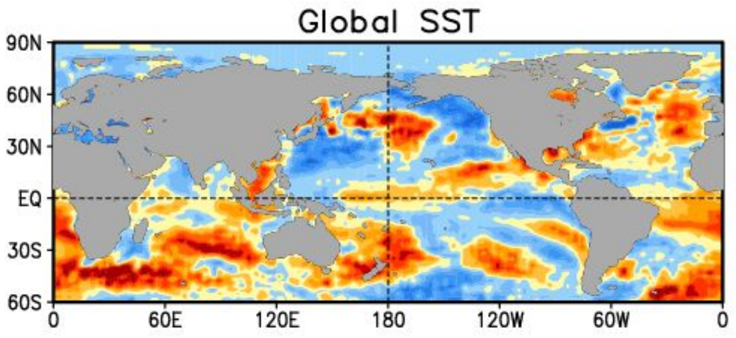
Same as control run, but the observed SST change between Nov2021-Mar2022 and Nov2020-Mar2021 is imposed over the Indian Ocean (30°S-30°N, 30°E-140°E) only.

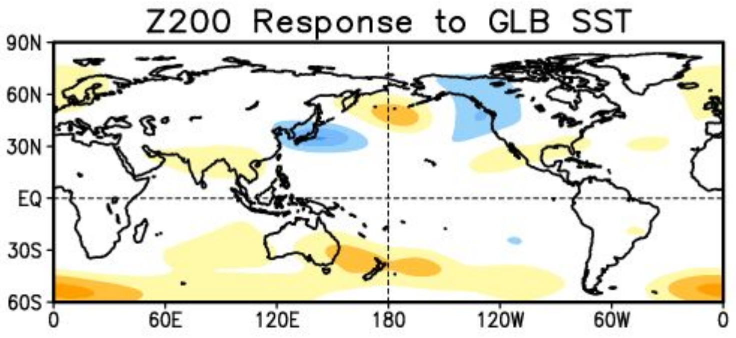
**all experiments are of 40-yr duration and utilize identical sea ice concentration, greenhouse gas and aerosol concentrations, thus these simulations isolate the sensitivity to changes in SST patterns**

# Sensitivity experiments

**Observed SST forcing** **Z200 Response**

**Global SST run**



# Sensitivity experiments

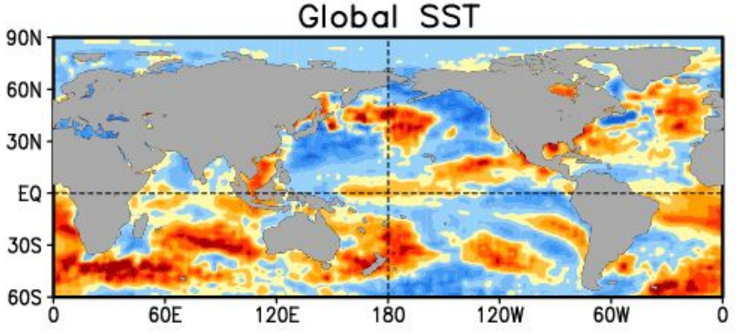
# AMIP ensemble mean

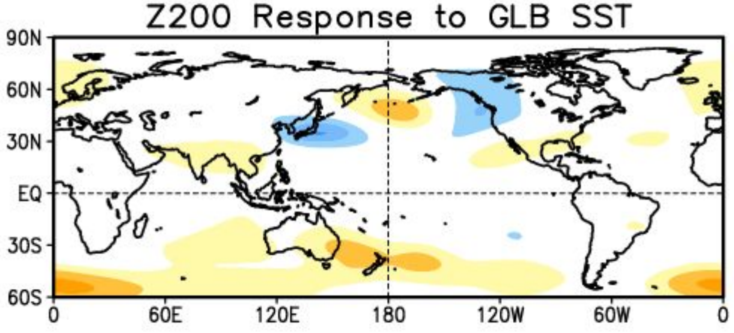
## Observed SST forcing

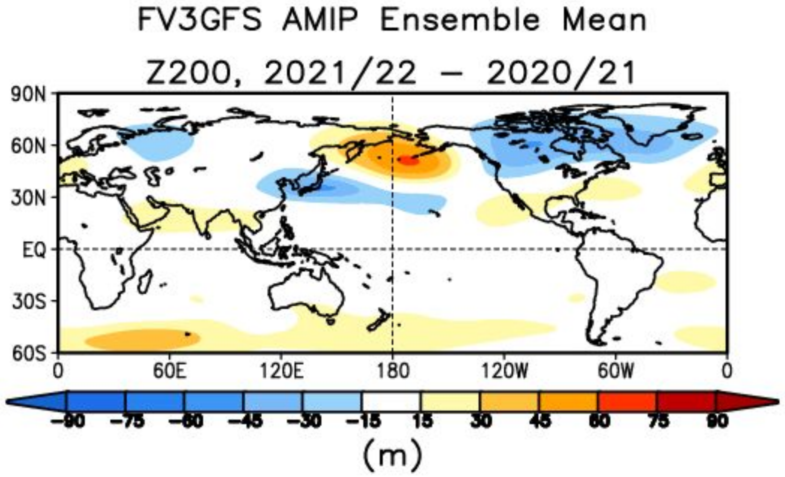
## Z200 Response

## Z200 Difference

**Global SST run**



# Sensitivity experiments

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## Observed SST forcing

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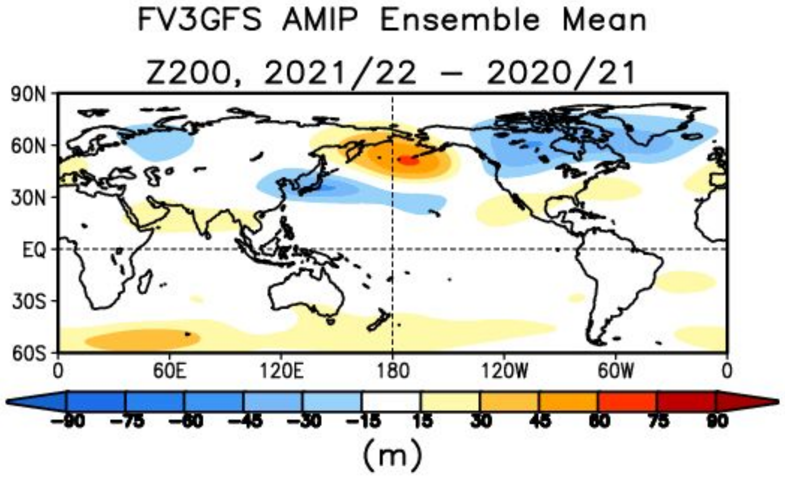
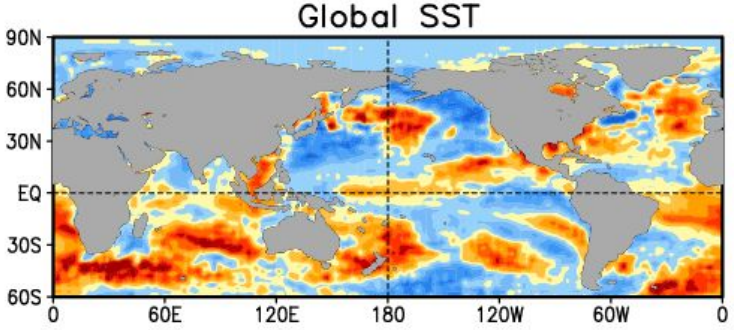
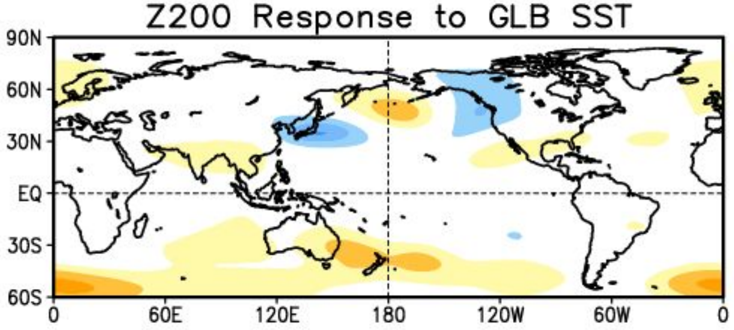
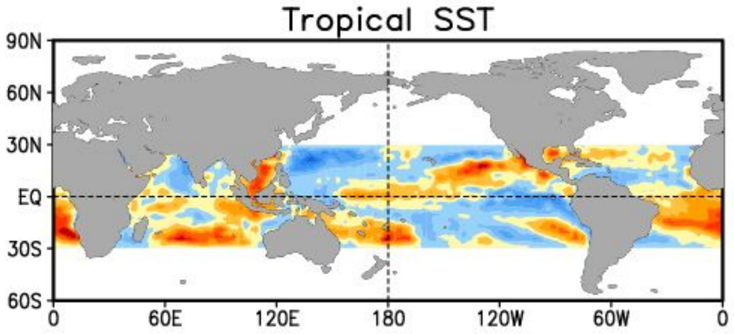


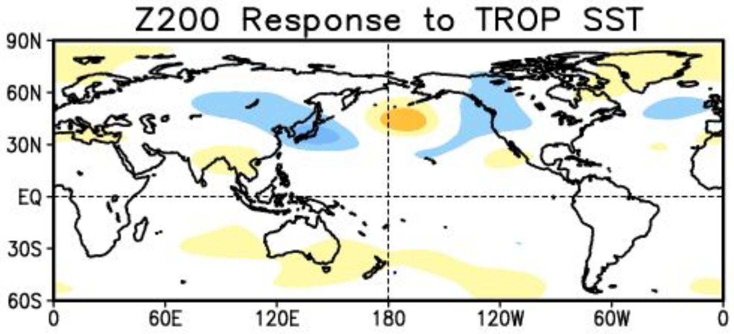

**Global SST run**




**Tropical SST run**



# Sensitivity experiments

# AMIP ensemble mean

## Observed SST forcing

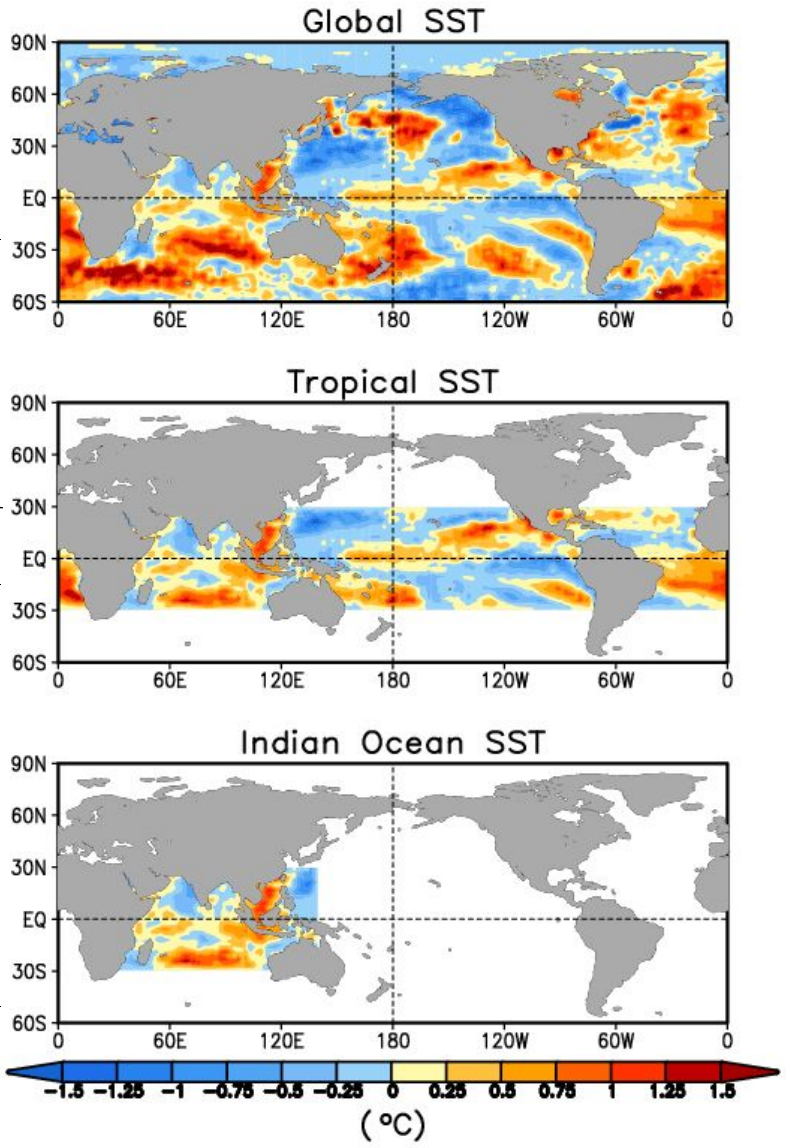
## Z200 Response

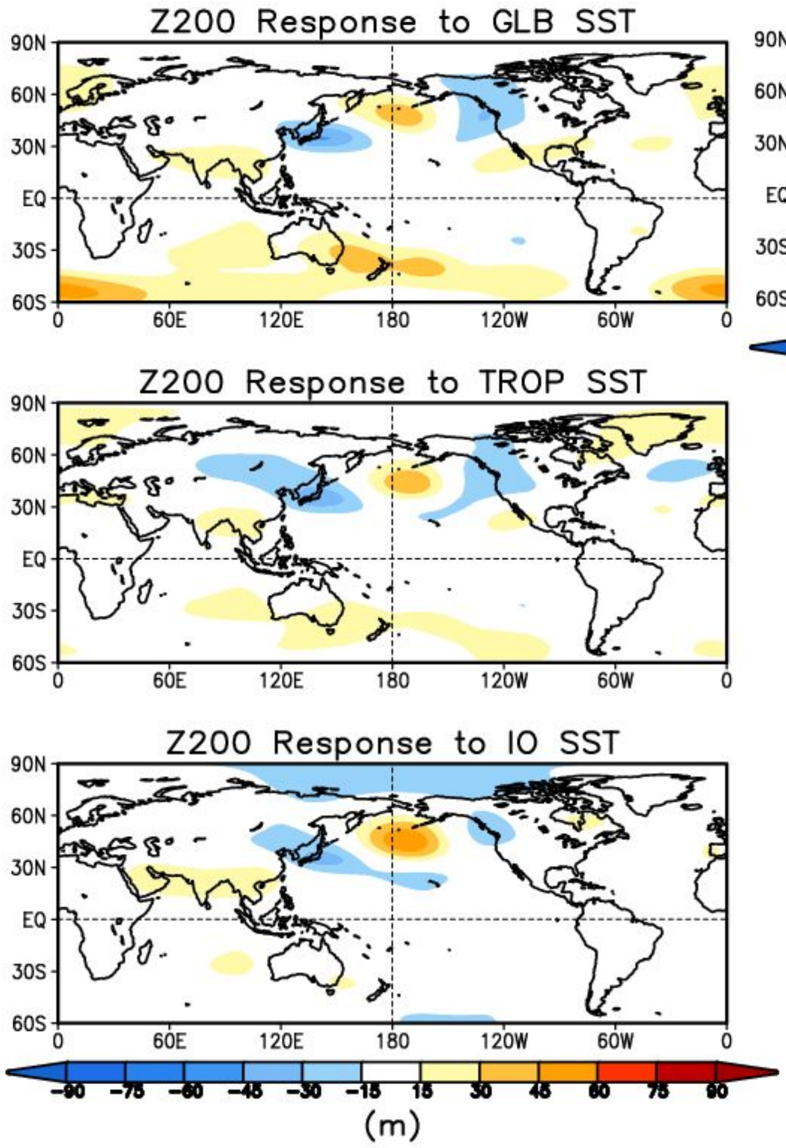
## Z200 Difference

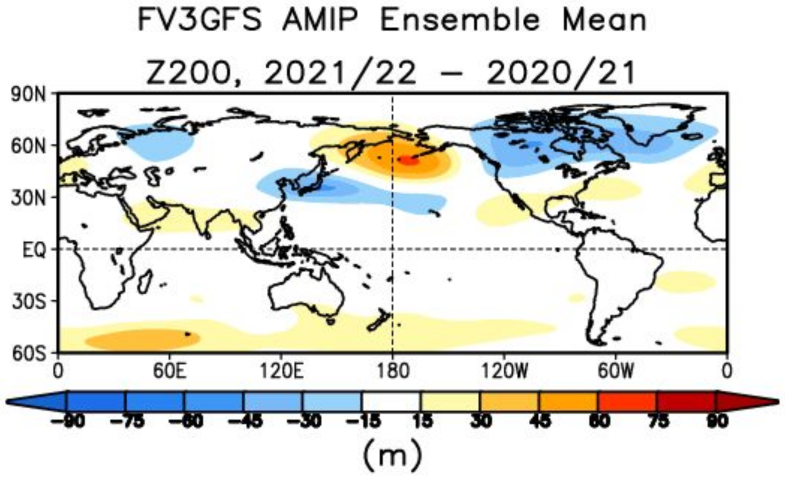
Global SST run

Tropical SST run

Indian Ocean SST run



# Sensitivity experiments

# AMIP ensemble mean

## Observed SST forcing

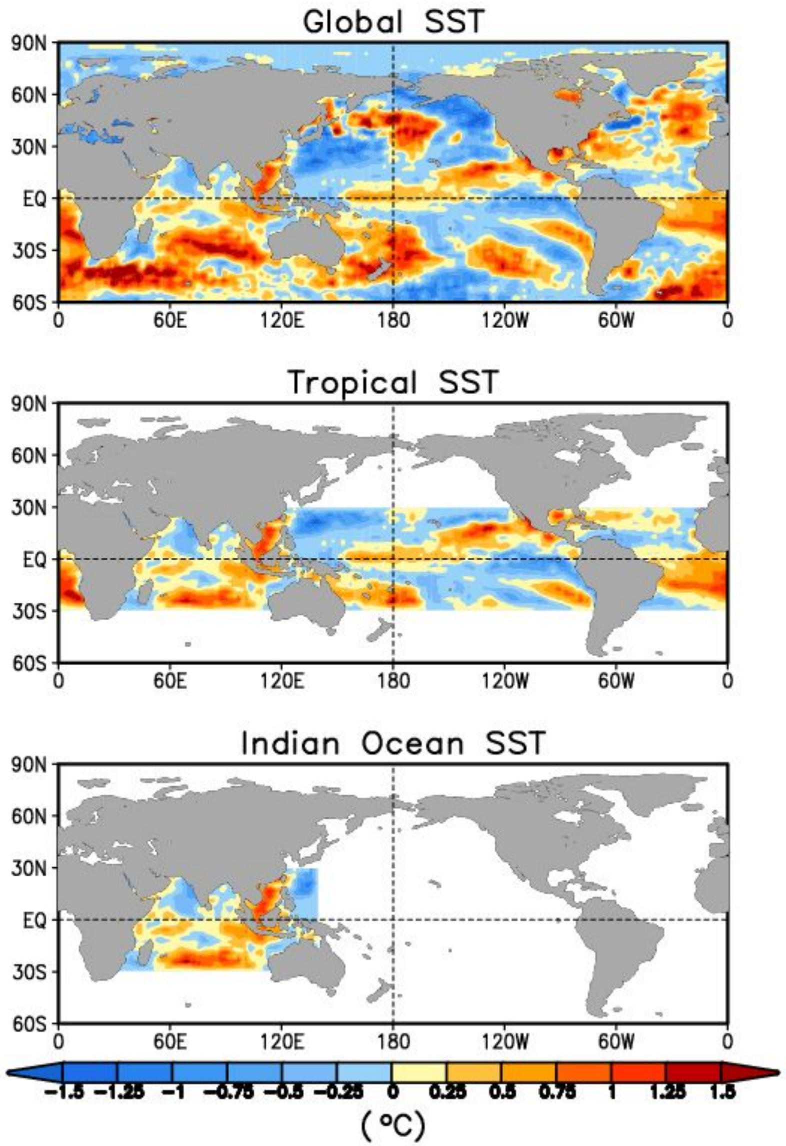
## Precip Response

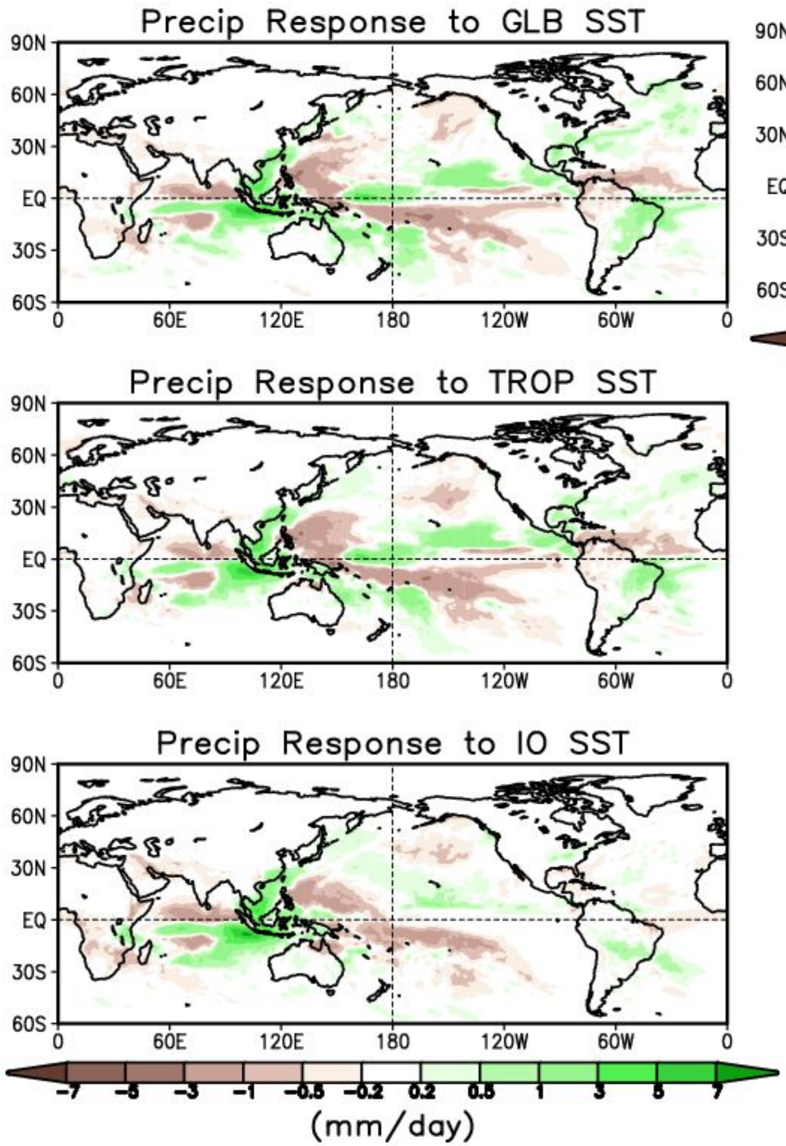
## Precip Difference

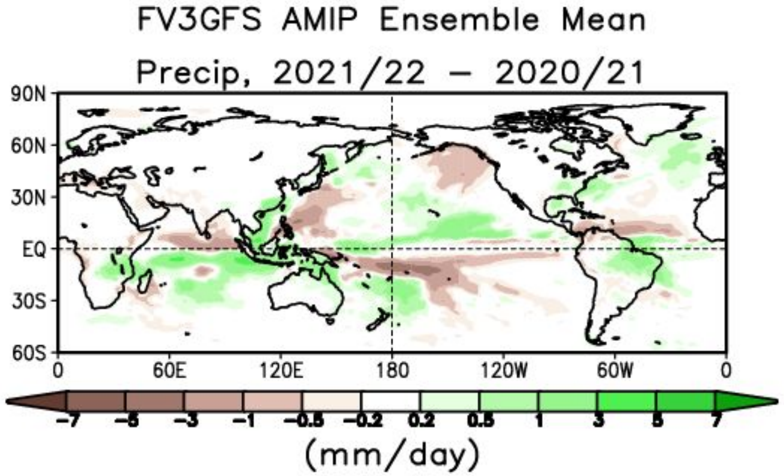
**Global SST run**

**Tropical SST run**

**Indian Ocean SST run**



# (3) What was the impact of errors in prediction of SST in NMME forecasts?

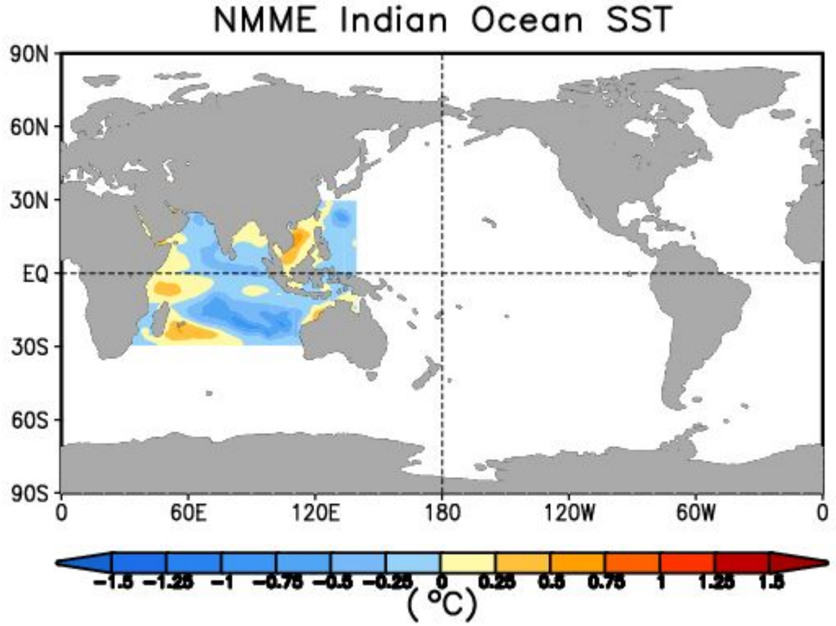
# Model experiment design

- **Perturbed run 4 ( NMME Indian Ocean SST run)**

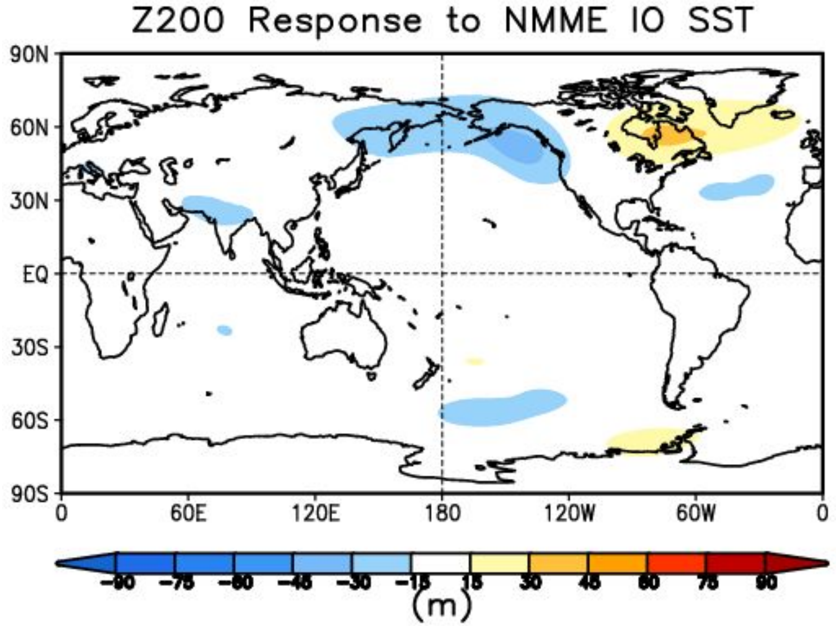
Same as control run, but NMME predicted SST change (November 2021-March 2022 averages minus November 2020-March 2021 averages) over the Indian Ocean region (30ºS-30ºN, 30ºE-140ºE) are added to the observed climatological SSTs of the control run, while all other forcings are unchanged.

# NMME Indian Ocean SST run

**Indian Ocean SST forcing**

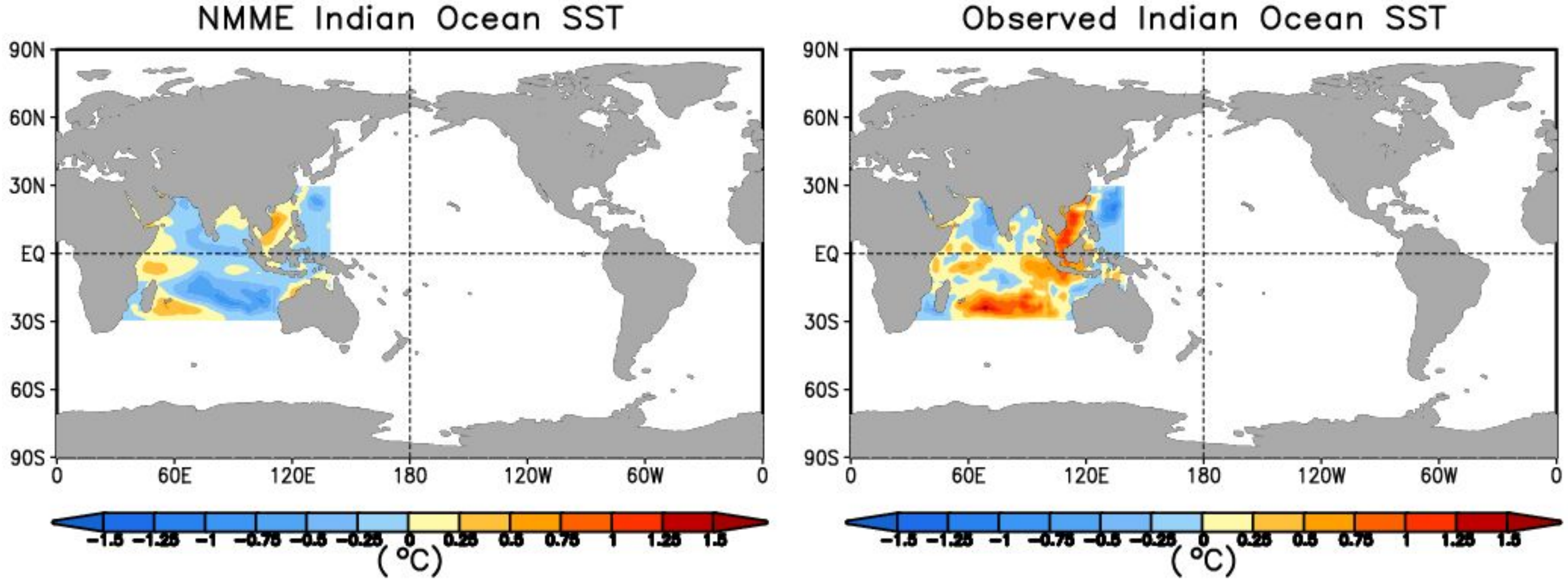



**Z200 Response**

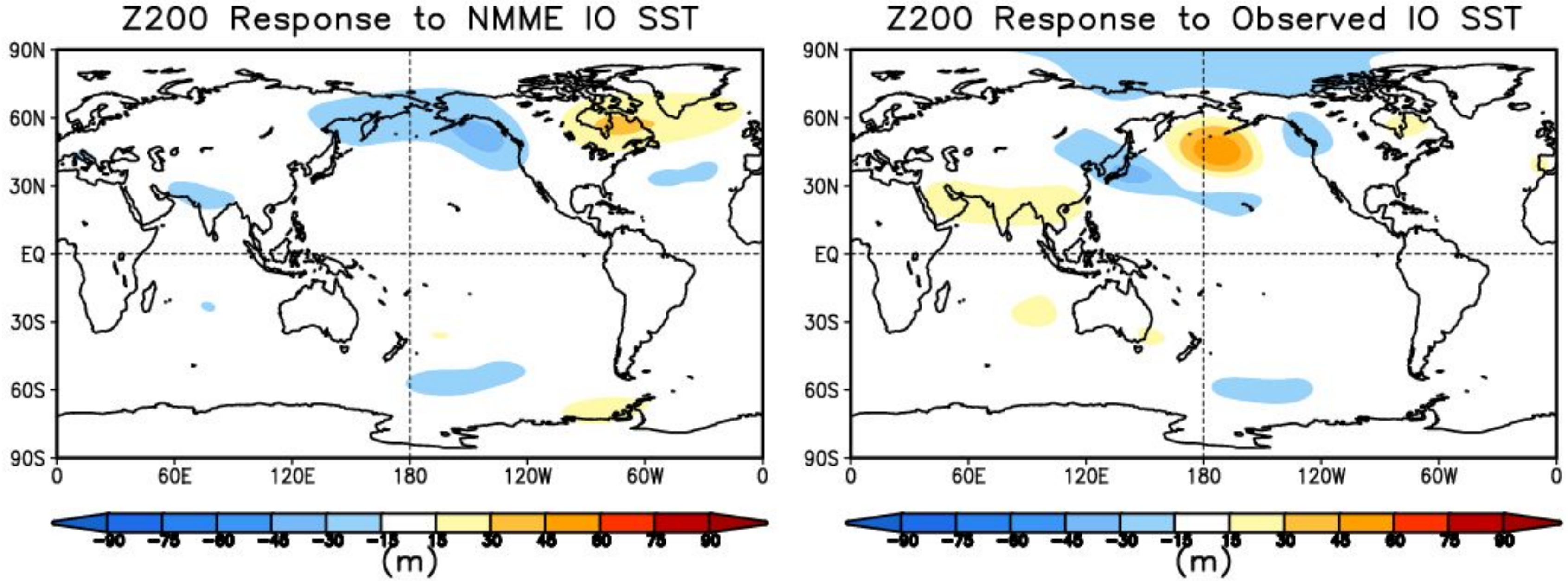


# NMME Indian Ocean SST run    OBS Indian Ocean SST run

**Indian Ocean SST forcing**



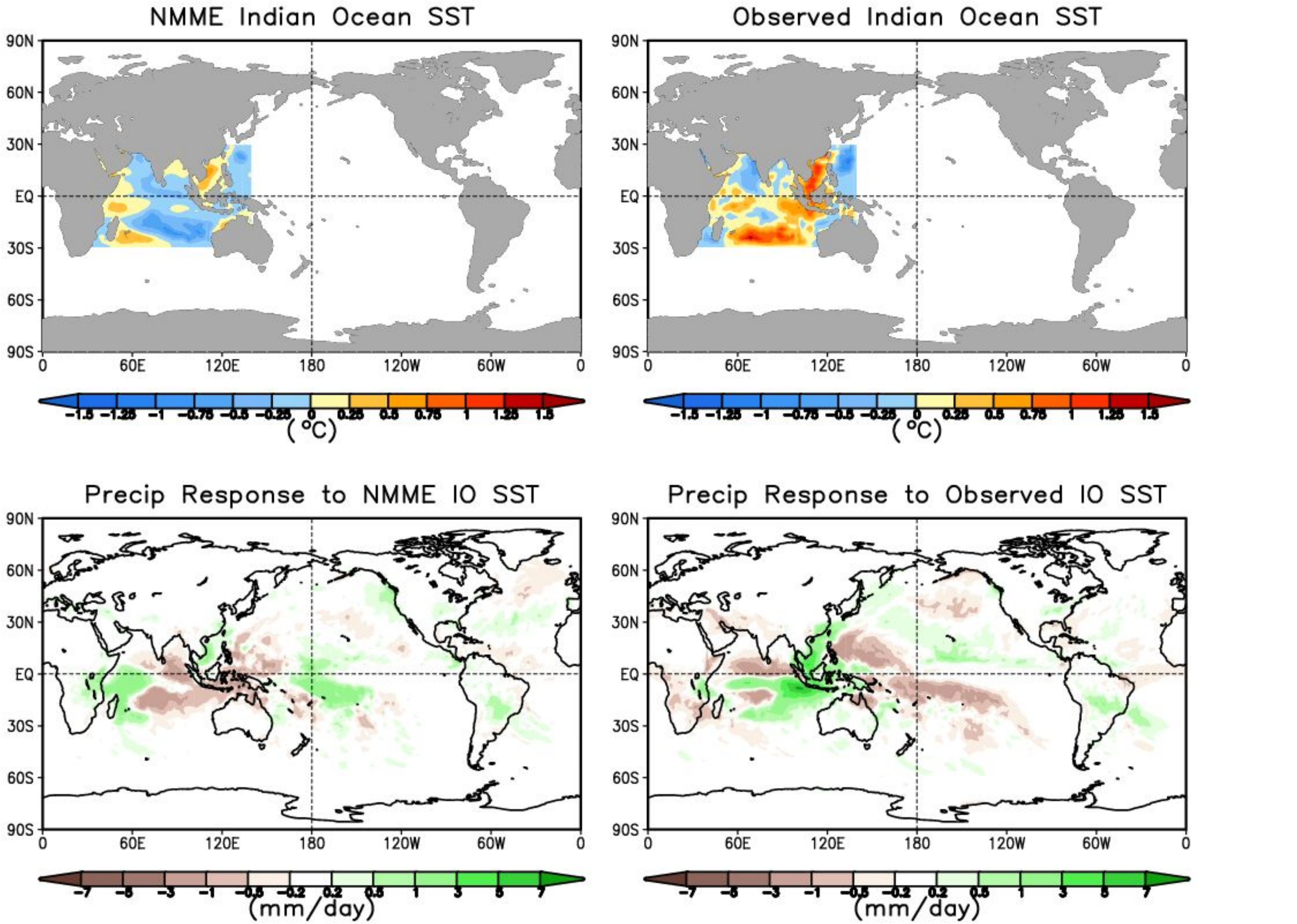

**Z200 Response**



## NMME Indian Ocean SST run | OBS Indian Ocean SST run

**Indian Ocean SST forcing**

**Precip. Response**



# Summary

- The difference in observed atmospheric anomalies for 2022 versus 2021 La Niña boreal winters featured a Northern Hemisphere tripole pattern.
- Indian Ocean SST contributed to the formation of observed tripole pattern, with internal atmospheric variability modulating its magnitude.
- Errors in SST predictions over the Indian Ocean led to the failure in predictions of the circulation changes in NMME forecasts.

# Thank you!

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Geophysical Research Letters

**RESEARCH LETTER**
10.1029/2023GL107301

**Key Points:**

- The difference in observed atmospheric anomalies for 2022 versus 2021 La Niña boreal winters featured a Northern Hemisphere tripole pattern
- Indian Ocean SST contributed to the formation of observed tripole pattern, with internal atmospheric variability modulating its magnitude
- Errors in SST predictions over the Indian Ocean led to the failure in predictions of the circulation changes in NMME forecasts

**Supporting Information:**

Supporting Information may be found in the online version of this article.

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## On the Role of Indian Ocean SST in Influencing the Differences in Atmospheric Variability Between 2020–2021 and 2021–2022 La Niña Boreal Winters

**Tao Zhang**[1,2] and **Arun Kumar**[2]

[1]ESSIC, University of Maryland, College Park, MD, USA, [2]NOAA/NCEP/Climate Prediction Center, College Park, MD, USA

**Abstract** The difference in observed atmospheric anomalies over the Northern Hemisphere winter between 2021–22 and 2020–21 La Niña years indicated a tripole pattern consisting of a Japan cyclone, a Bering Sea anticyclone, and a cyclone over the North American continent. This feature, however, was not replicated in the North American Multi-Model Ensemble (NMME) forecasts. A set of model sensitivity experiments was performed to better understand the cause of this discrepancy. The results revealed the possible role of the influence of sea surface temperature (SST) anomalies, particularly over the Indian Ocean, on the observed circulation differences that was further modulated by internal atmospheric variability. The failure in predicting circulation changes in NMME was next attributed to the errors in SST predictions over the Indian Ocean and highlights the need for improvements in SST forecasts over this region.

**Plain Language Summary** The tropical SST anomalies associated with the El Niño-Southern Oscillation (ENSO) are known to influence the global atmospheric circulation and are the major source of skill in U.S. seasonal predictions. As the cold phase of ENSO, La Niña features below-normal SST anomalies and suppressed convection over the equatorial central and eastern Pacific. Such a tropical heating distribution favors the formation of the atmospheric circulation pattern that has a roughly opposite effect on U.S. surface climate compared to El Niño, the warm phase of ENSO, although the effect is not strictly symmetric. For the recent two La Niña boreal winters of 2020–21 and 2021–22, the observed circulation patterns differed, but dynamical seasonal prediction failed to replicate this feature. Understanding the cause for the discrepancy of circulation changes between prediction and observations is of fundamental importance for the improvement of seasonal

# Additional slides

# Background

**The extratropical atmospheric anomalies can be influenced by the following factors:**

- the atmospheric internal variability (Kumar and Hoerling 1995; Zhang et al. 2014)

- extratropical SST forcing (Beaudin et al. 2023)

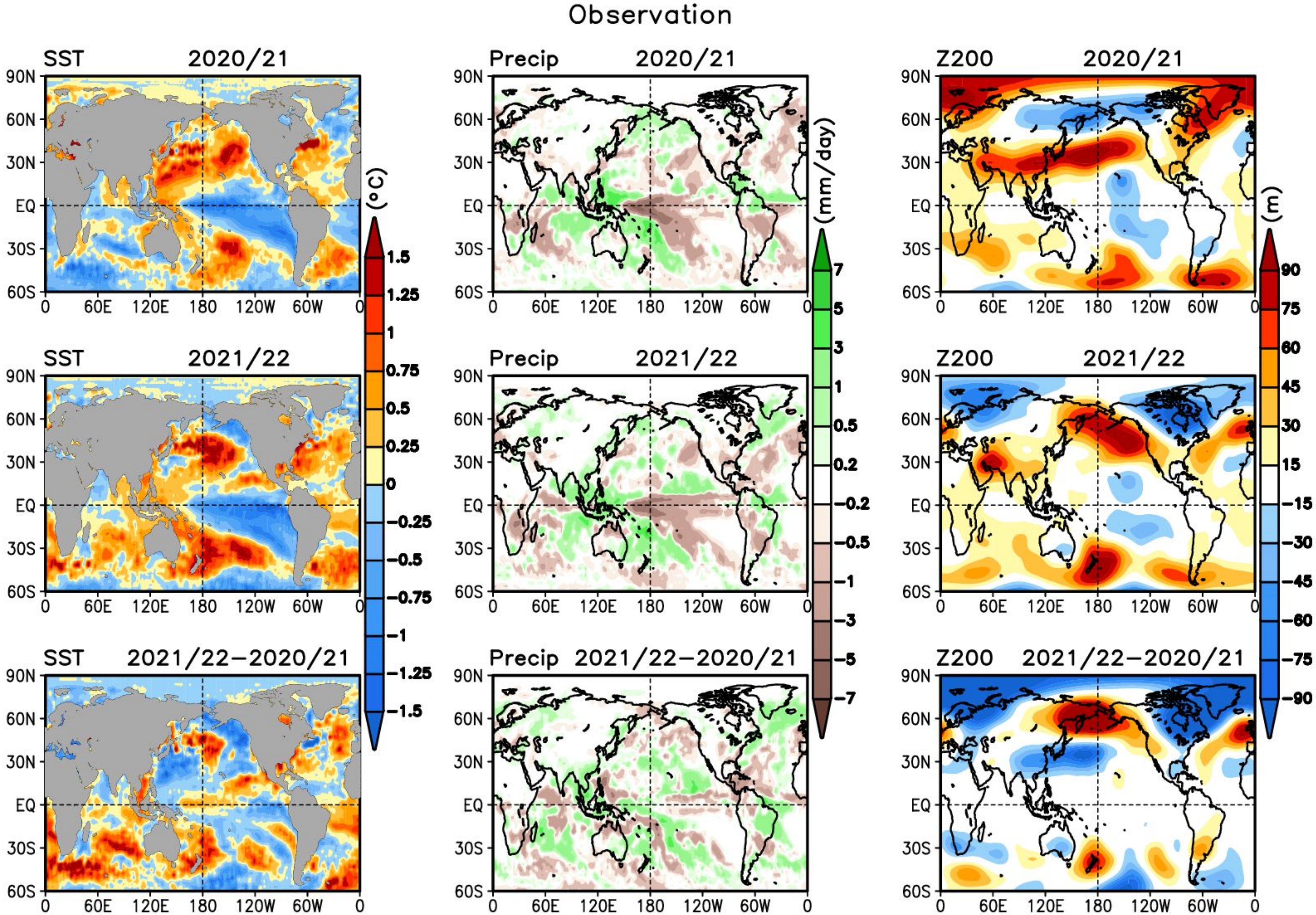
- SST anomalies in the tropical Indian and Pacific Ocean basins (Hoerling and Kumar 2002; Annamalai et al. 2007).

# Observed SST (left), Precip (Center) and Z200 (right)

**2020/21**

**2021/22**

**2021/22
Minus
2020/21**

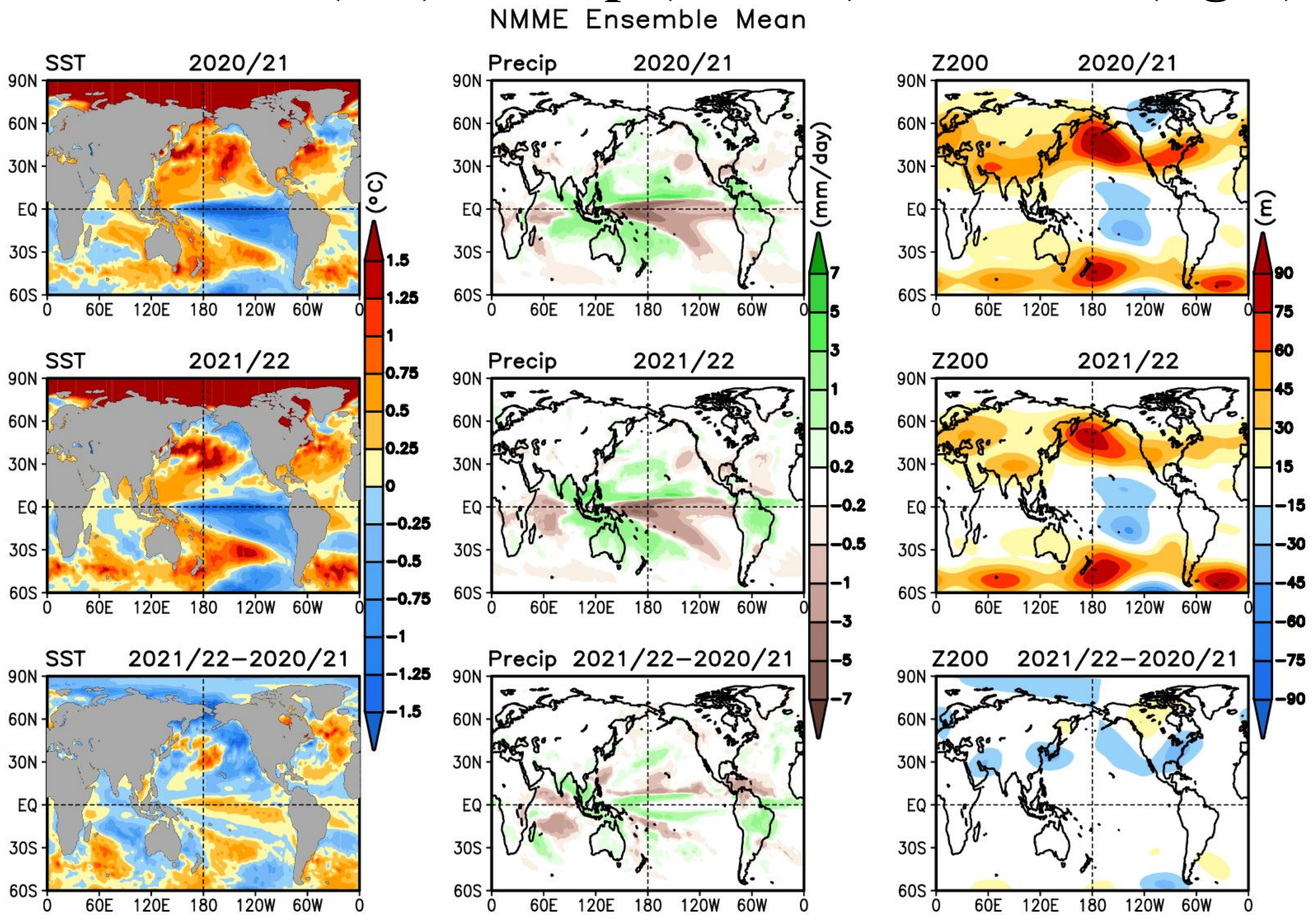


# NMME SST (left), Precip (Center) and Z200 (right)

2020/21

2021/22

2021/22 Minus 2020/21



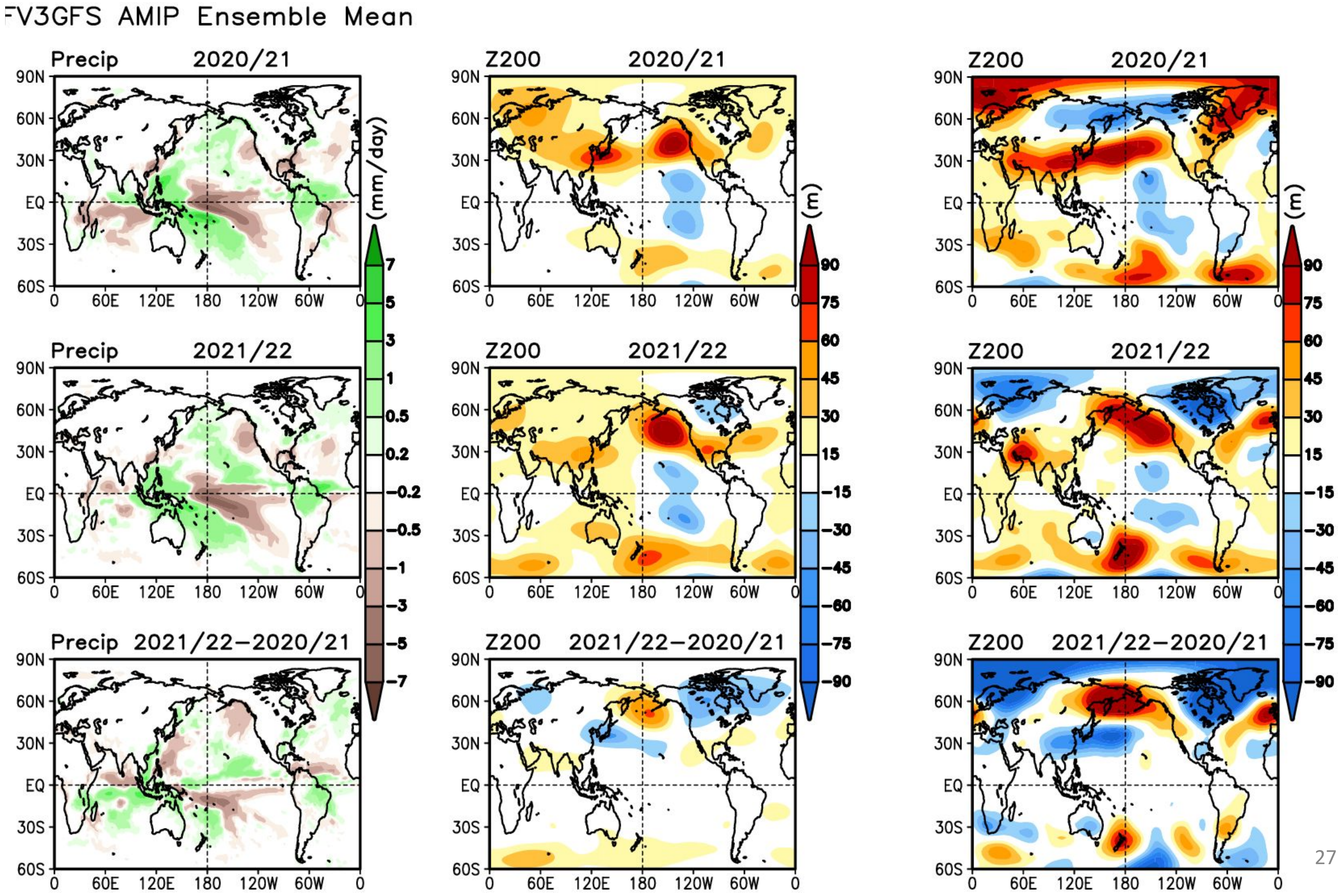
# AMIP ensemble mean Precip and Z200

# Observed Z200

2020/21

2021/22

2021/22
Minus
2020/21



# Procedures to generate 10,000 model estimates of Z200 difference from FV3GFS 100 AMIP runs

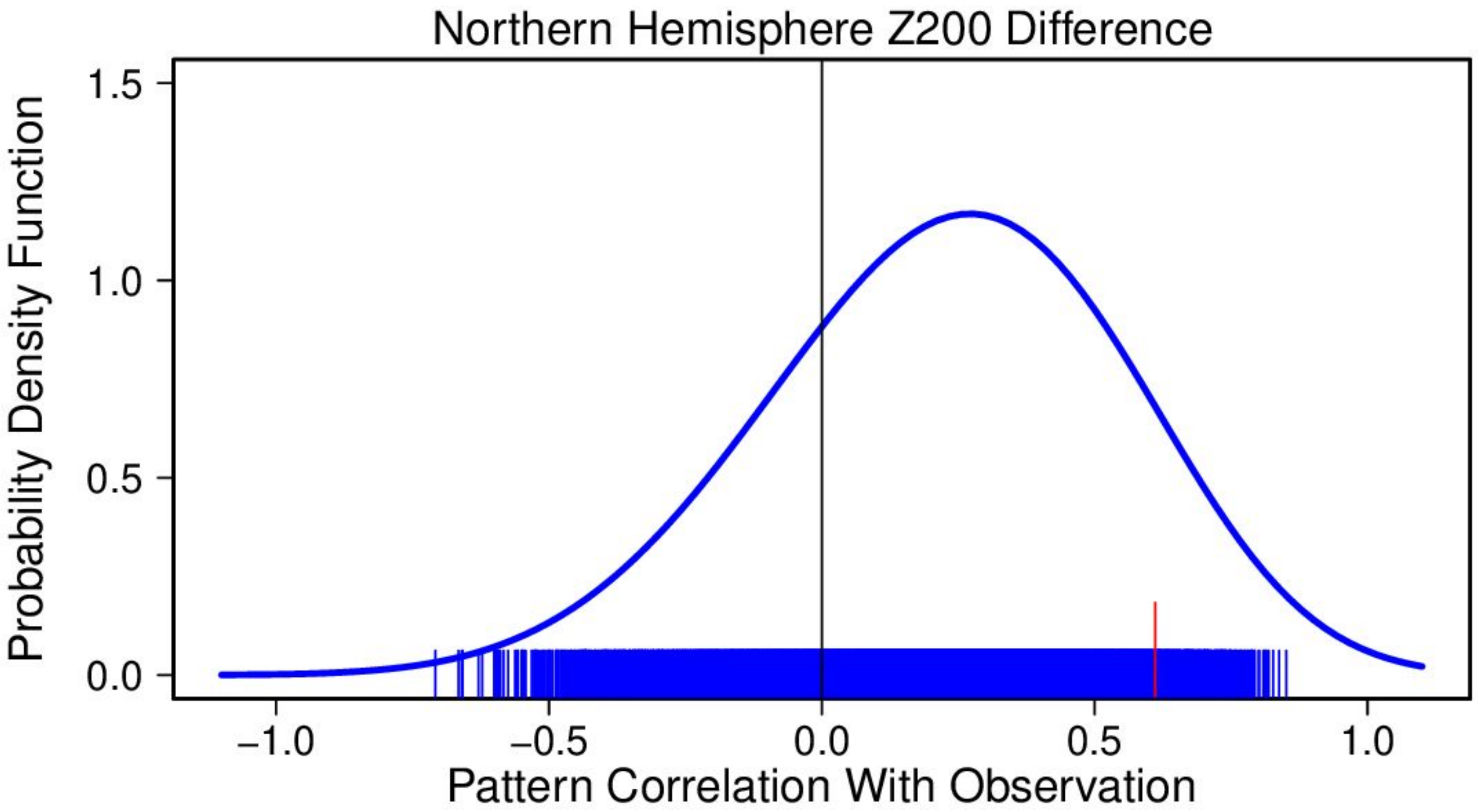
**Step 1.** From each run, 200-hPa height for 2021 (LN21.R1 to LN21.R100) and for 2022 (LN22.R1 to LN22.R100) averaged over for November 2020-March 2021 and for November 2021-March 2022 respectively is first obtained.

**Step 2.** An estimate of 200-hPa height *change* is calculated as the difference between 2022 and 2021 5-month averages

**Step 3.** For each of the one hundred independent 2022 averages (LN22.R1 to LN22.R100), one hundred model samples of 200-hPa height change can be calculated by utilizing the one hundred 2021 averages as follows: (LN22.R1 - LN21.R1,…..,LN22.R1 - LN21.R100,….,
LN22.R100 - LN21.R1,….., LN22.R100 - LN21.R100).

**Step 4.** This approach results in a total of 10,000 (100x100) model estimates of 200-hPa height change.

# PDF of Pattern Correlations with Observation from 10,000 model samples for NH Z200 difference for AMIP simulations




- Observed difference is well within the possible range of outcomes in AMIP simulations
- Largest correlation values reach about 0.9
- The PDF of correlation has a positive skewness.
- **The** Correlation of difference in ensemble mean response with observation is 0.61 (red long line)