Improved Simulation of Midlatitude Climate in a New Channel Model Compared to Contemporary Global Climate Models

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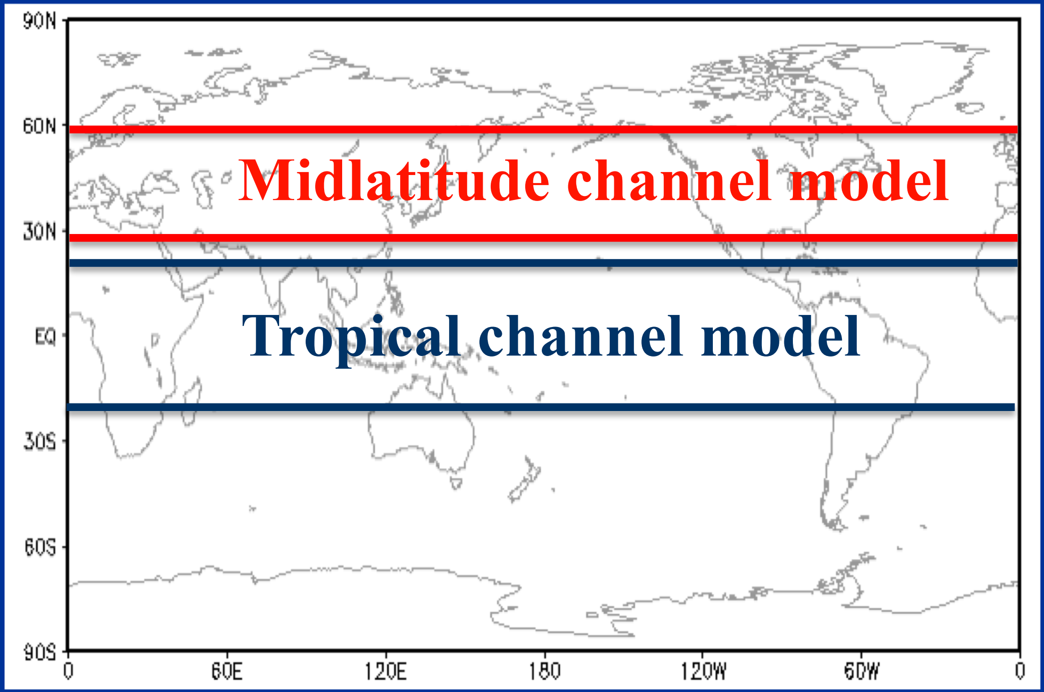
Background

Channel Model

- Channel models are zonally global but meridionally confined
- Tropical channel models (TCMs) have been in use for a while (Ray et al 2009, JAS)
- The main advantages are:

(i) higher resolution than GCMs
(ii) fewer lateral boundary conditions than regional model,
(iii) controlling the influence from low or high latitude through meridional boundaries



- Performance of channel models against GCMs is not known

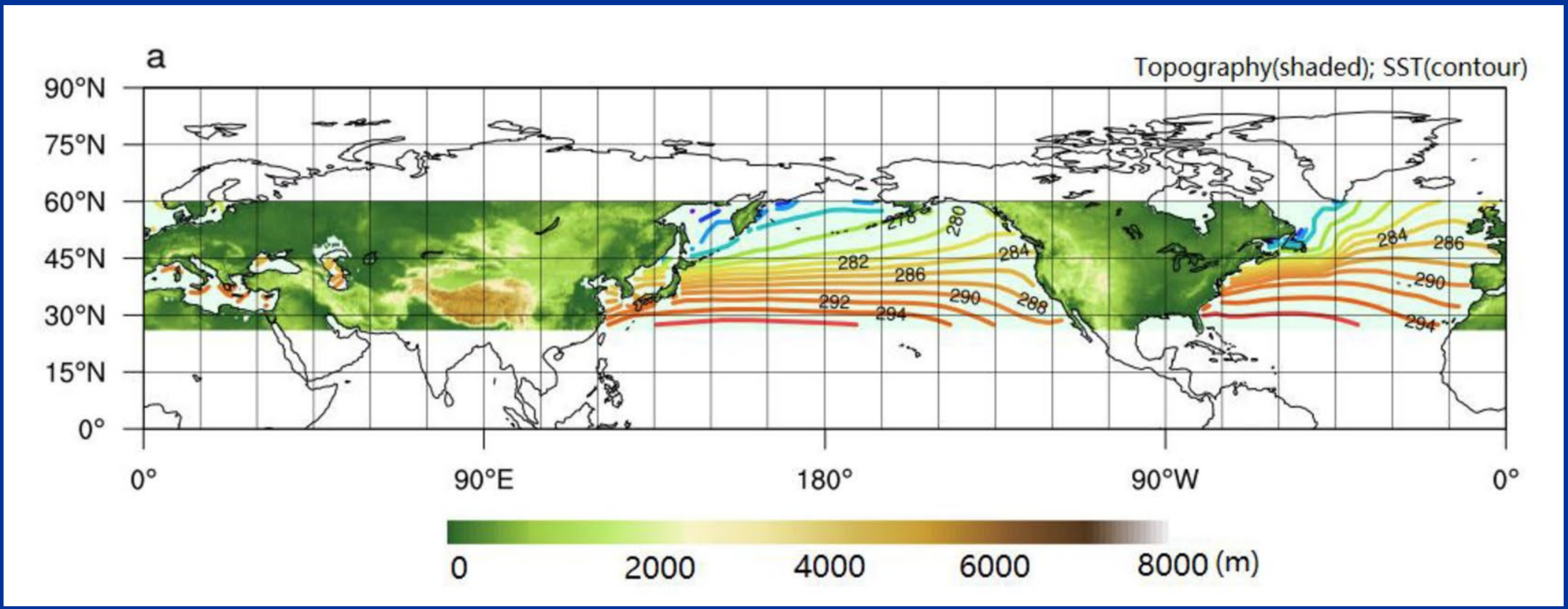
Motivation

- To explore whether a mid-latitude channel model (MCM) can outperform contemporary GCMs
- To explore the geographical regions where tropical (MJO) forcings are most effective in modulating mid-latitude circulation

Model, Data, and Method

MCM simulations

Model: WRF 3.8 forced by ERA-Interim
Mercator projection (0–360E, 26N-60N)
Horizontal Resolution: ~0.33° Vertical Layers: 40
1 December 1999 to 31 December 2003; output: 6 hourly



Model, Data, and Method

Observed/Reanalysis data

ERA-Interim reanalysis (~ 79 km; 60 layers)
GPCP and TRMM

Atmospheric GCMs

20 Atmospheric Model Intercomparison Project (AMIP5) models
horizontal resolution range: $0.19 \times 0.19^\circ$ to $2.8 \times 2.8^\circ$
vertical layers: 18 to 60

Method

All data interpolated to $2.5 \times 2.5^\circ$ and 17 vertical layers
Monthly data
Multi-model ensemble (MME) based on 20 AMIP5 models

Results

- **Performance of a midlatitude channel model (MCM) compared to AGCMs**

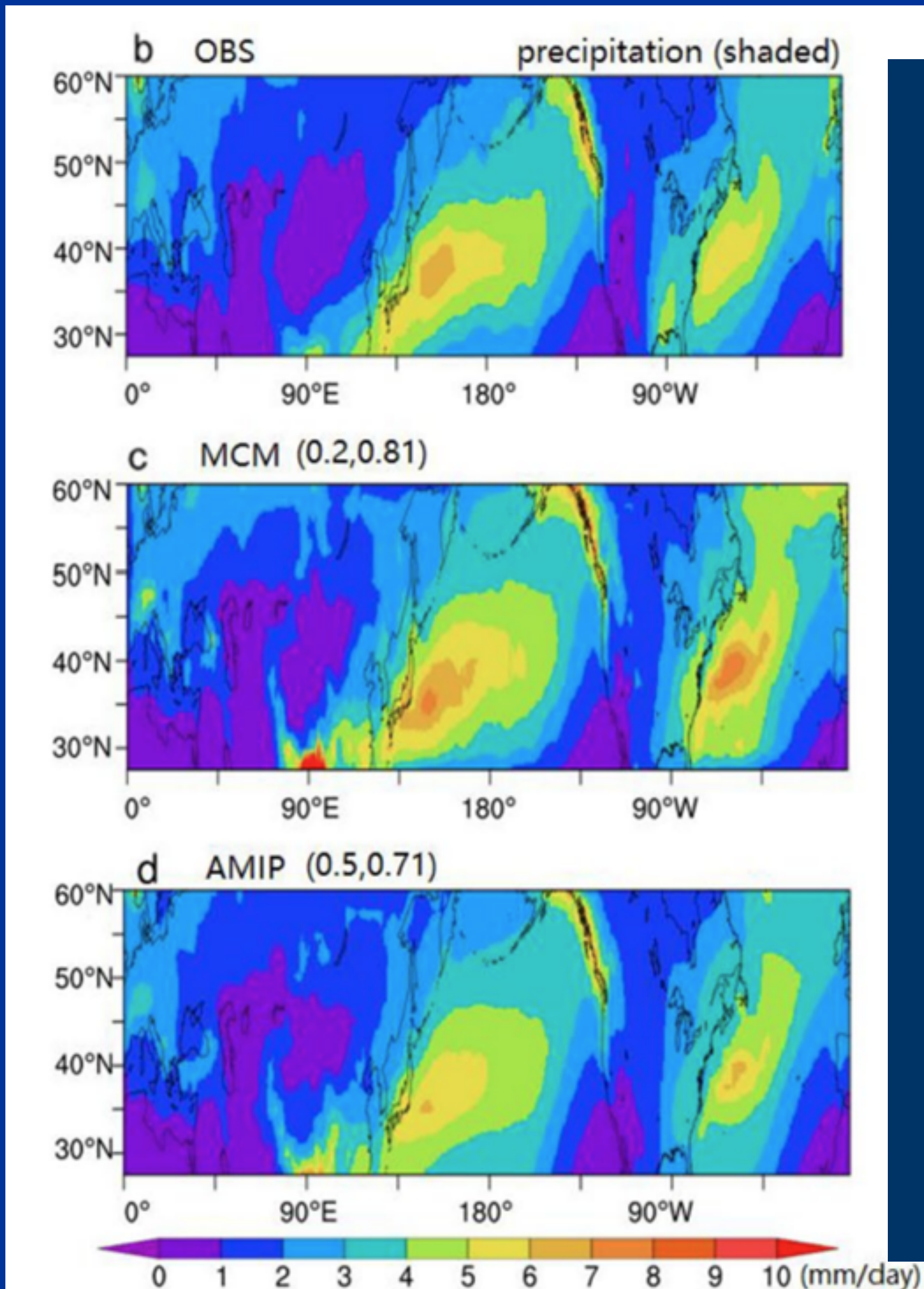
  - Comparison with observation/reanalysis and multi-model ensemble (MME) based on 20 AMIP5 models

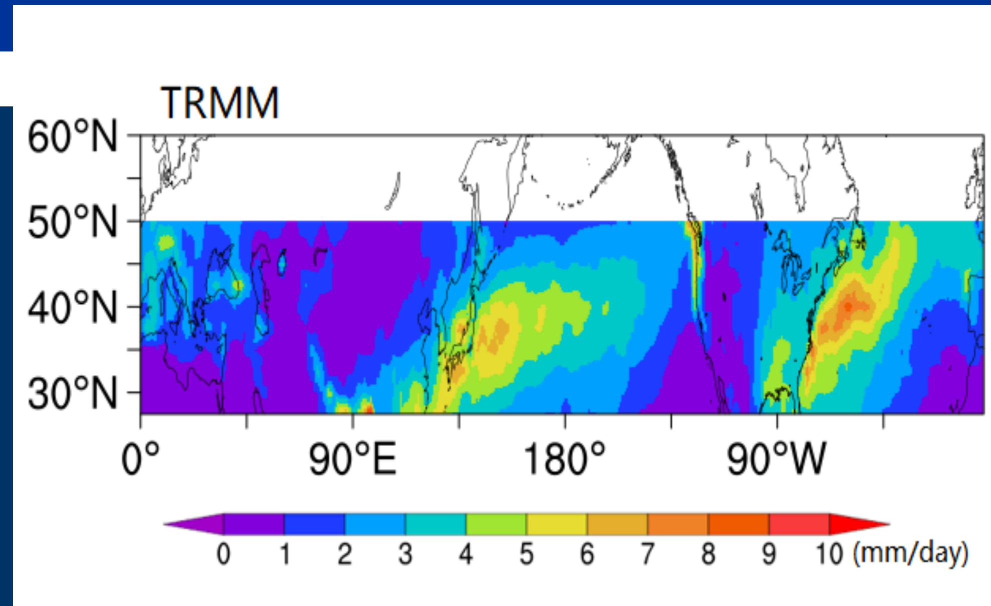
  - Possible reasons for MCM's superior/inferior performance

- **Exploring the role of MJO on midlatitude circulation**

  - Geographical regions where the MJO influence is predominant

Performance of MCM

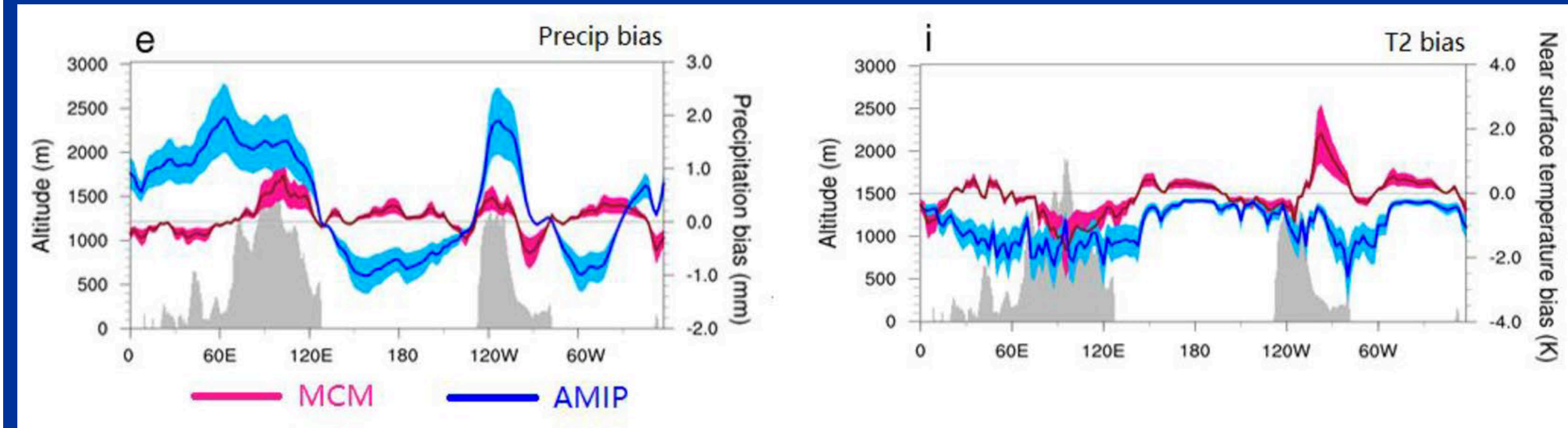




- Realistic spatial structure
- Differences in observations over western oceans

		MCM	AMIP
Precipitation (mm day^{-1})	Bias	0.2	0.5
	RMSE	0.5	1.0
	CC	0.81	0.71

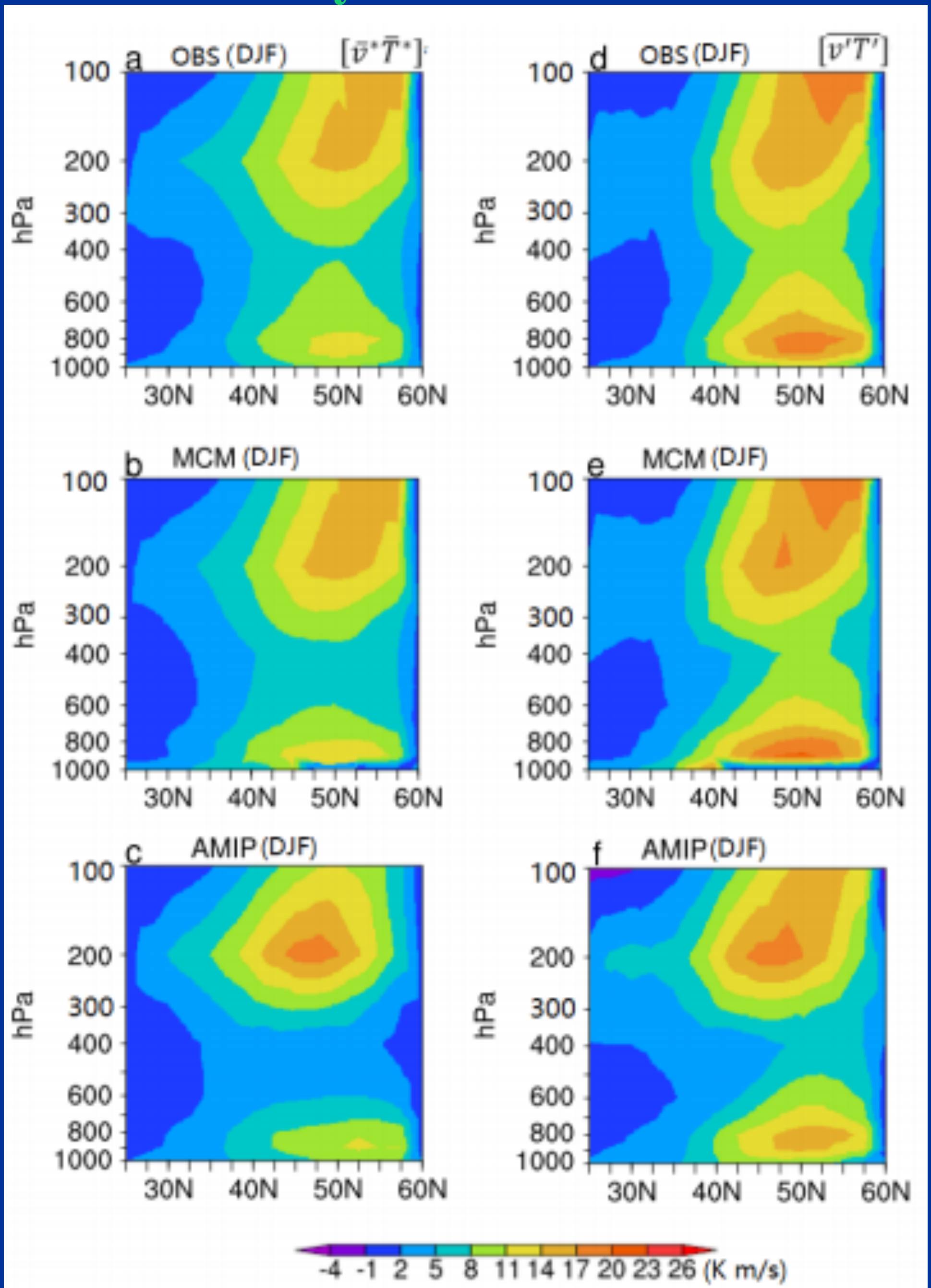
Performance of MCM



- Biases are larger over land
- AMIP models consistently underestimate T2
- MCM outperforms AMIP for climatology and seasonal cycle
- What about eddies?

Heat Transport by Eddies

Stationary **Transient**



- Zonally averaged meridional heat transport:

$$[\overline{vT}] = [\bar{v}][\bar{T}] + [\bar{v}^*\bar{T}^*] + [\overline{v'T'}]$$

- v=meridional velocity
- T=temperature
- [ ]= zonal averaging
- $\bar{}$ =time averaging
- * =departure from zonal averaging
- $'$ =departure from time mean
- Mean circulations

- **Peak in transport by stationary eddies displaced southward and downward in AMIP**
- **Weaker heat transport by transients in AMIP**

Possible reasons behind MCM's superior performance

- **Higher resolution in MCM than most AMIP models:** 18 out of 20 AMIP models had coarser resolution than MCM. Only 2 models (GFDL-HIRAM and MRI-AGCM3) had higher resolution
- **Use of observed (reanalysis) boundary conditions**

To test resolution dependence:

- **A new MCM simulation with coarser resolution (1.0×1.0) was compared against 5 AMIP models with higher resolution (0.5×0.5)**
  - **This coarse resolution MCM outperforms ensemble based on 5 higher-resolution AMIP**
  - **MCM also performs better than GFDL-HIRAM**

Results

- **Performance of a midlatitude channel model (MCM) compared to AGCMs**

  - Comparison with observation/reanalysis and multi-model ensemble (MME) based on 20 AMIP5 models

  - Possible reasons for MCM's superior performance

- **Exploring the role of MJO on midlatitude circulation**

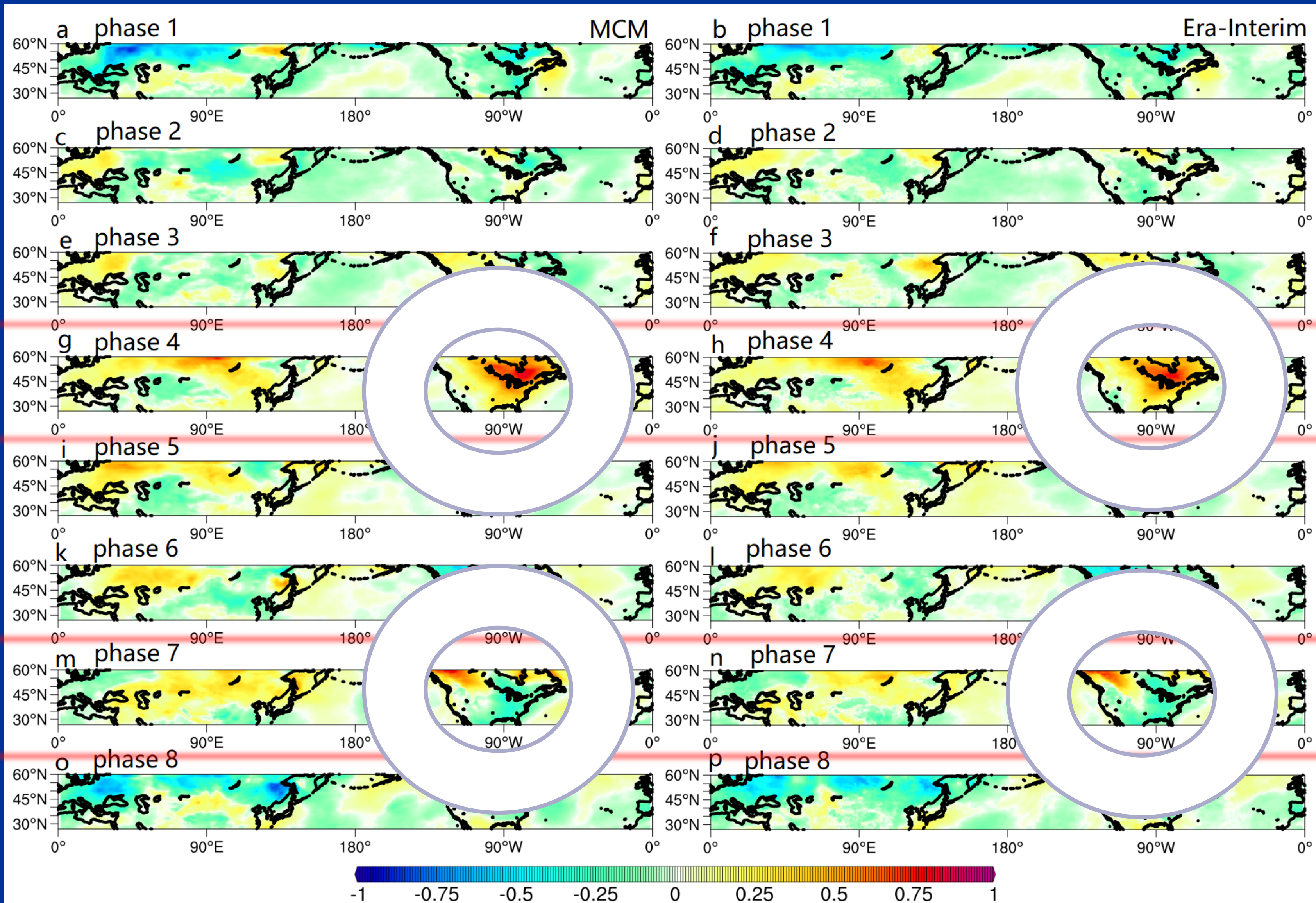
  - Geographical regions where the MJO influence is predominant

Role of MJO on midlatitude

Control: December 1999 to February 2000

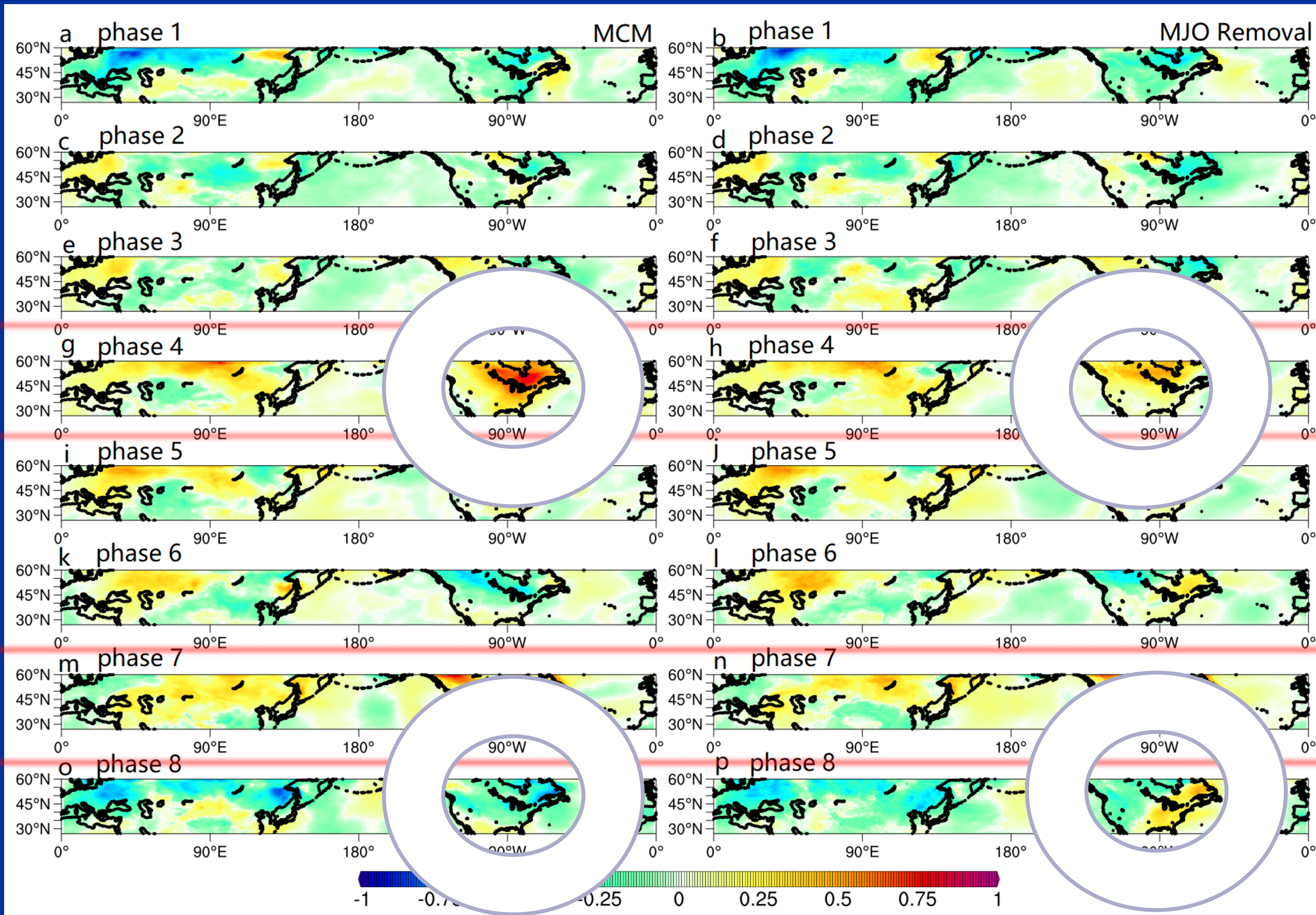
MJO_removal: Same as control, but lateral boundary conditions based on annual cycle from reanalysis.

Anomalous T2 at different MJO phases (Dec 1999- Feb 2000)



- Most GCMs struggle to capture the magnitude of anomalies likely due to erroneous MJO (Stan et al. 2022, BAMS)
- MCM simulation was realistic;

Control vs MJO_Removal (Dec 1999- Feb 2000)



- Magnitude of anomalies weakened during MJO active phases over North America
- Significant difference in MJO inactive phases is possibly due to higher frequency events

Summary

- A midlatitude channel model (MCM) based on WRF outperforms an ensemble of 20 contemporary AGCMs.

- A coarse resolution (1x1) MCM outperforms an ensemble of higher resolution (~0.5x0.5) AMIP models.

- The MCM captures the midlatitude circulation at different MJO phases, and points to geographical regions where MJO impact may be predominant.

THANK YOU

Ray P., X. Zhou, H. Tan, J. Dudhia, and M.W. Moncrieff, 2021: Improved simulation of the mid-latitude climate in a new channel model compared to contemporary GCMs, *Geophys. Res. Lett.*, 48, e2021GL093297. https://doi.org/10.1029/2021GL093297

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Extra Slides

Parameterizations

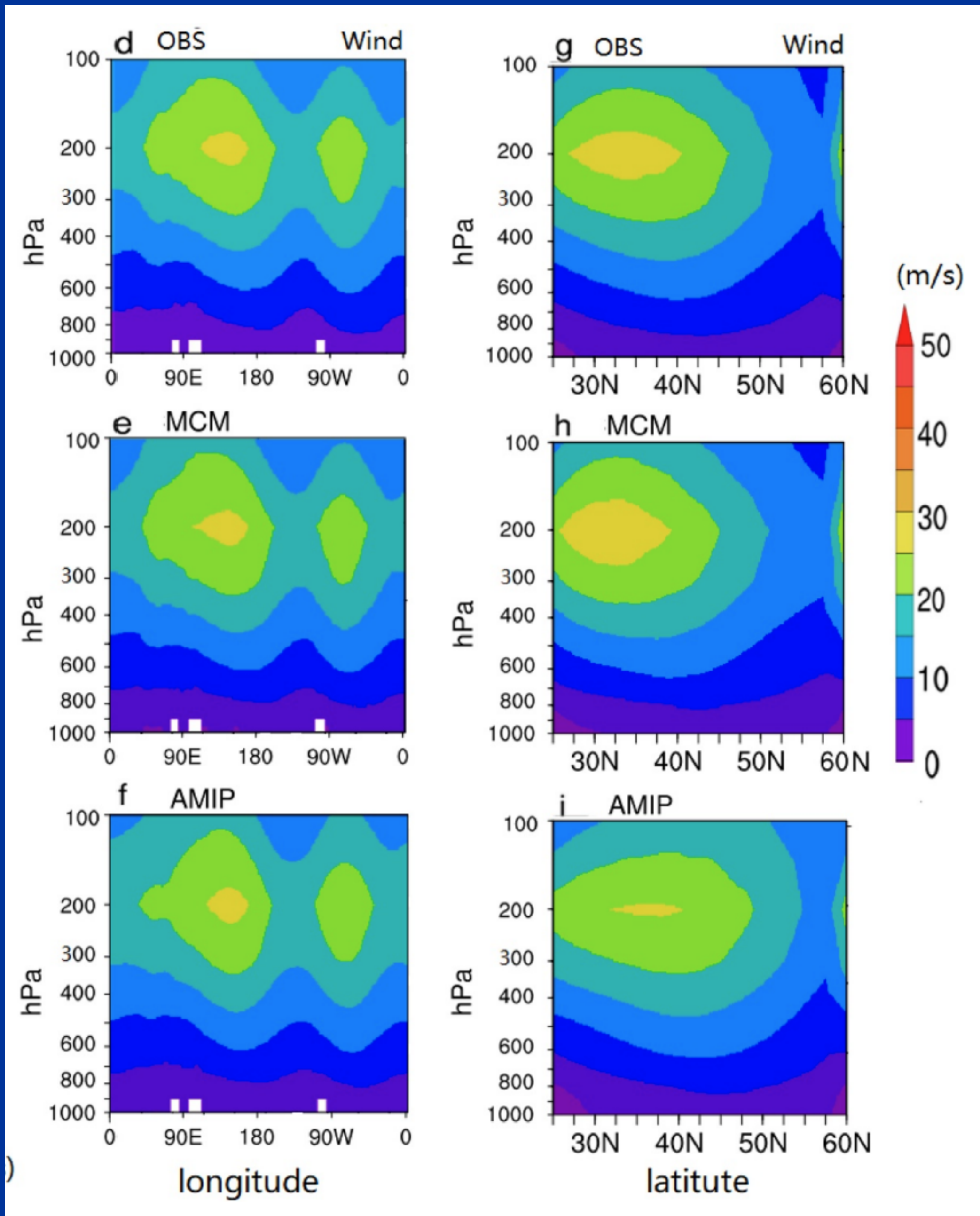
- Kain-Fritsch scheme for cumulus parameterization
- Noah land surface model for surface layer parameterization
- Rapid radiative transfer model scheme for longwave radiation
- Goddard scheme for shortwave radiation
- Yonsei scheme for planetary boundary layer
- WRF Single Moment 6 for microphysics

Performance of MCM

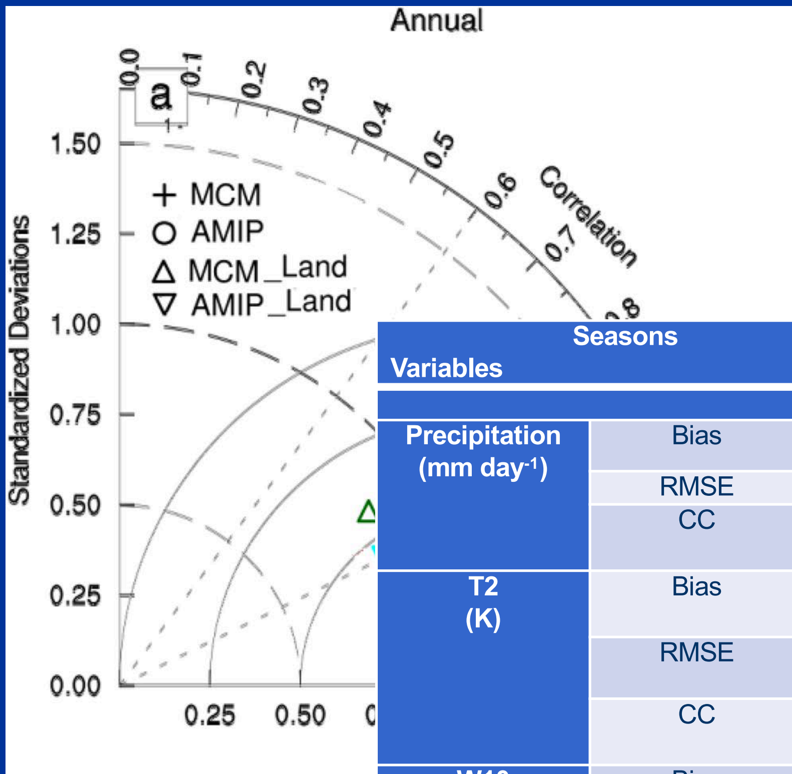
Variables / Seasons		Annual		DJF		JJA	
		MCM	AMIP	MCM	AMIP	MCM	AMIP
Over Land							
Precipitation (mm day^{-1})	Bias			0.2	**0**		
	RMSE			0.4	**0.2**		
	CC						
T2 (K)	Bias						
	RMSE						
	CC						
W10 (m s^{-1})	Bias						
	RMSE						
	CC						
Wind$_{850hPa}$ (m s^{-1})	Bias						
	RMSE						
	CC						
Wind$_{200hPa}$ (m s^{-1})	Bias						
	RMSE						
	CC						

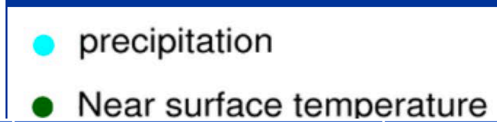
- What about eddies?

Performance of MCM



Performance of MCM





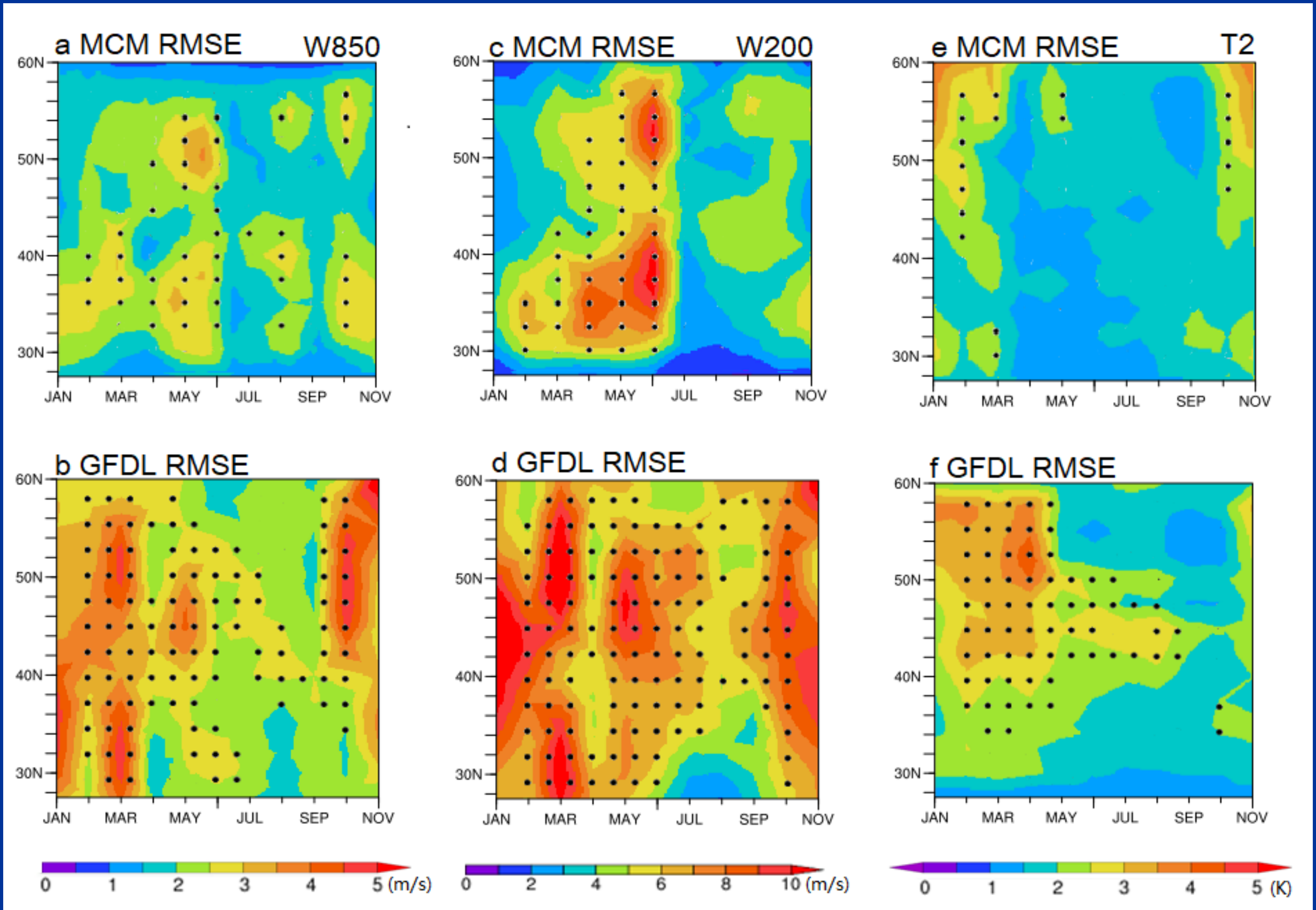
Variables	Seasons	Annual MCM	Annual AMIP	DJF MCM	DJF AMIP	JJA MCM	JJA AMIP
Over Land							
Precipitation (mm day^{-1})	Bias	0.3(0.3)	0.6(0.5)	0.2(0.2)	**0(-0.1)**	0.2(0.2)	0.7(0.7)
	RMSE	0.5(0.5)	1.1(1.0)	0.4(0.5)	**0.2(0.2)**	0.6(0.6)	1.5(1.3)
	CC	0.81(0.80)	0.7(0.72)	0.75(0.75)	0.63(0.66)	0.85(0.84)	0.7(0.71)
T2 (K)	Bias	-0.1(-0.1)	-0.4(-0.3)	-0.1(-0.1)	-0.3(0.2)	-0.2(-0.2)	-0.5(-0.4)
	RMSE	0.4(0.4)	0.8(0.6)	0.3(0.3)	0.6(0.4)	0.6(0.6)	1.0(0.8)
	CC	0.87(0.86)	0.85(**0.88**)	0.82(0.82)	0.80(0.81)	0.93(0.93)	0.87(0.89)
W10 (m s^{-1})	Bias	-0.3(-0.3)	-0.5(-0.4)	-0.5(-0.5)	-0.7(-0.6)	-0.2(-0.2)	-0.4(-0.4)
	RMSE	1.1(1.1)	1.6(1.4)	1.5(1.5)	1.9(1.7)	0.8(0.8)	1.3(1.2)
	CC	0.92(0.92)	0.90(0.91)	0.91(0.90)	0.87(0.89)	0.93(0.92)	0.91(0.91)
$Wind_{850hPa}$ (m s^{-1})	Bias	-0.2(-0.3)	-0.4(-0.4)	-0.4(-0.5)	-0.7(-0.6)	0.1(0.1)	0.2(0.2)
	RMSE	1.2(1.4)	2.9(2.7)	1.5(1.7)	3.7(3.4)	0.8(0.9)	2.1(1.9)
	CC	0.94(0.93)	0.93(0.94)	0.93(0.93)	0.92(0.92)	0.92(0.91)	0.9(0.9)
$Wind_{200hPa}$ (m s^{-1})	Bias	0.7(0.7)	1.3(1.1)	0.9(0.9)	1.4(1.2)	0.5(0.5)	1.1(0.9)
	RMSE	2.5(2.6)	4.7(4.3)	3.1(3.2)	4.9(4.4)	1.9(2.1)	4.1(3.5)
	CC	0.77(0.76)	0.76(0.76)	0.81(0.80)	0.78(0.79)	0.76(0.76)	0.75(**0.77**)

Possible reasons behind MCM's superior performance

MCM versus GFDL-HIRAM

MCM

AMIP



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- Channel models are zonally global but meridionally confined.
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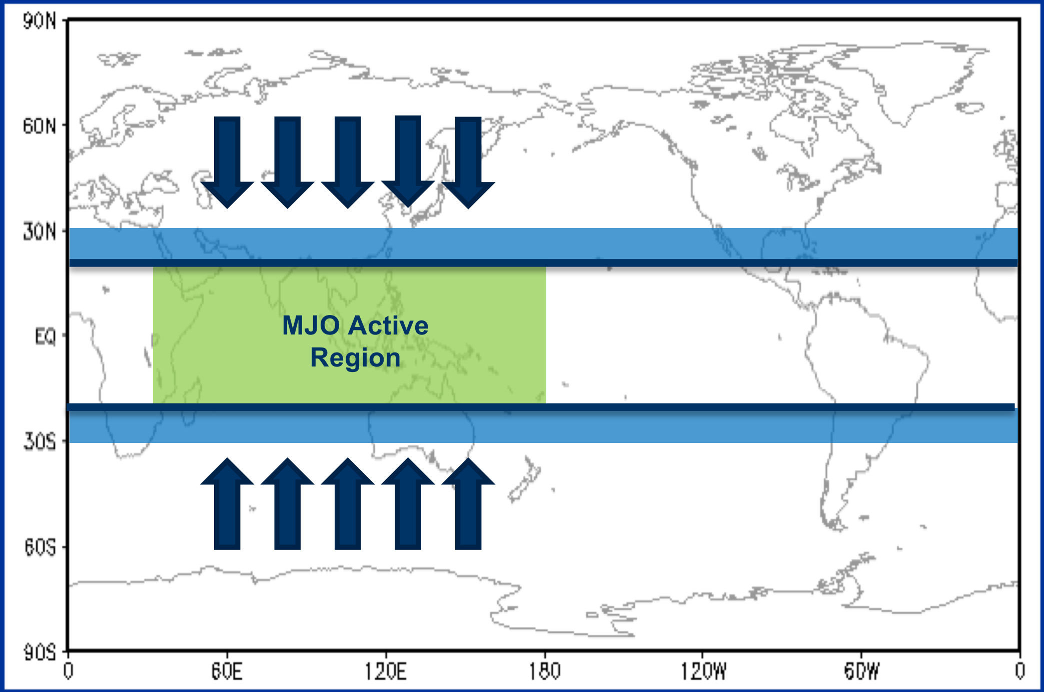
- Performance of TCMs against GCMs is not known.

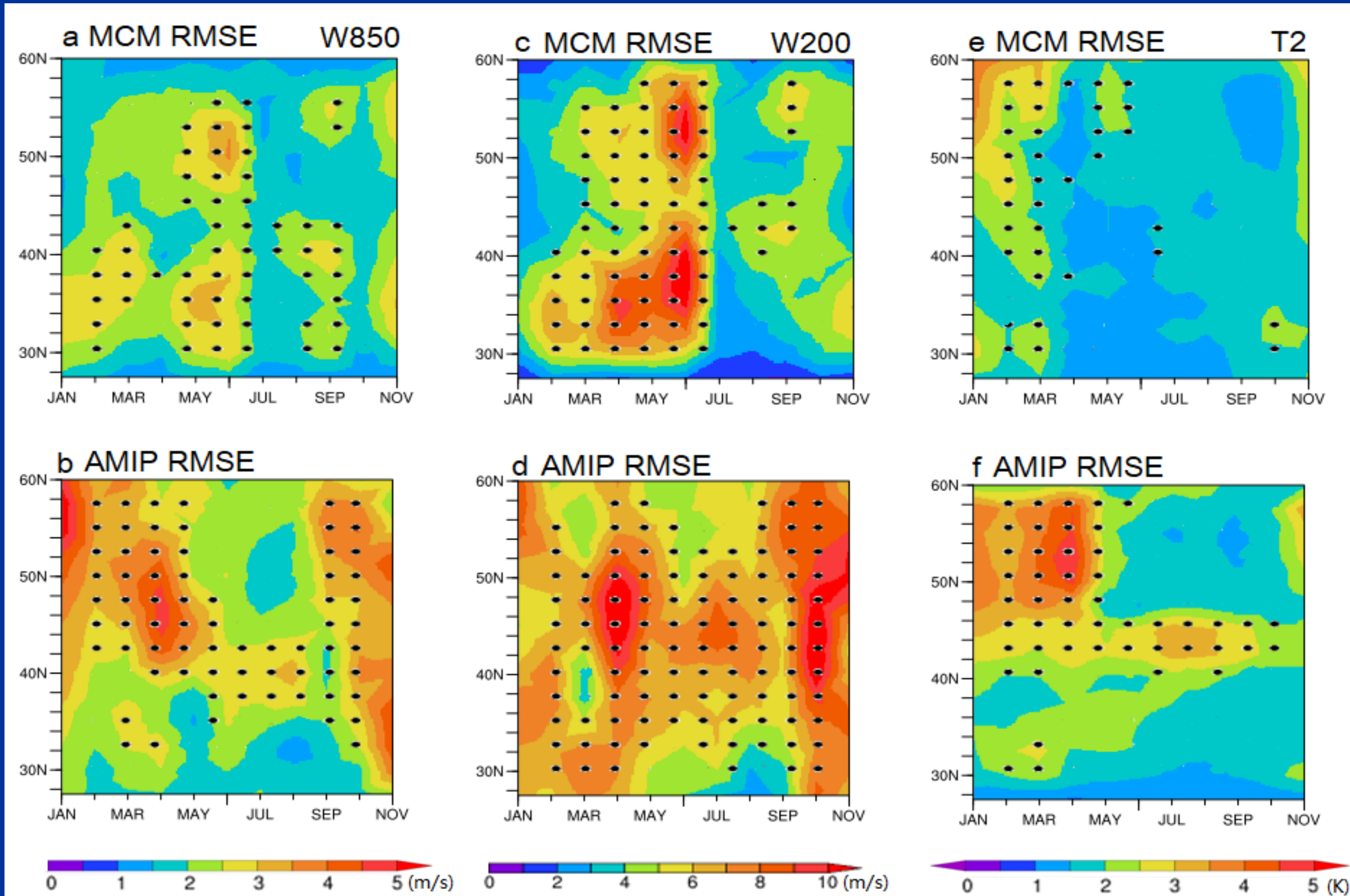


Possible reasons behind MCM's superior performance

Coarse-resolution MCM versus higher-resolution AMIP models

MCM
(1° res)

AMIP
(~0.5° res)



- MCM outperforms ensemble based on 5 higher-resolution AMIP
  - Also performs better than GFDL-HIRAM

Role of MJO on midlatitude (MJO_Removal – Control)