Model Diversity in Future Wintertime Circulation Change in the North Pacific

Isla Simpson
Climate and Global Dynamics Laboratory
National Center for Atmospheric Research

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35 CMIP5 Models

DJF season

- **PAST** = 1979-2005 of *historical*
- **FUTURE** = 2070-2099 of *RCP8.5*
- All available ensemble members
700hPa zonal wind
Multi-Model Mean

Past Climatology

- Local Jet Maximum

Simpson et al (2014)
700hPa zonal wind
Multi-Model Mean

- Past Climatology

- Local Jet Maximum

Future-Past difference

Simpson et al (2014)
700hPa zonal wind
Multi-Model Mean

Past Climatology

Local Jet Maximum

Future-Past difference

Simpson et al (2014)
EOF analysis (across models) of zonal wind response
EOF analysis (across models) of zonal wind response

EOF1, 37.5% of variance explained
Use the EOF Index as a measure of a models behaviour in the extra-tropical west Pacific

25% most positive EOF1 = Poleward Models
25% most negative EOF1 = Not Poleward Models

(9 models in each group)
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference

Why this distinct behavior between these groups of models?
Connection to the Tropics?
250hPa Divergence and Divergent Meridional Wind

Divergence (Past)

ci=1e-6

Multi-Model Mean Past Climatologies

Divergence

Divergent v (Past)

ci=0.4

Divergent v
250hPa Divergence and Divergent Meridional Wind

Divergence (Past)

- $ci=1e-6$

Divergent v (Past)

- $ci=0.4$

Divergence (Future-Past)

- $ci=5e-7$

Divergent v (Future-Past)

- $ci=0.2$
Divergence (Future-Past)

250hPa Divergence

Multi-Model Mean (Future-Past)
250hPa Divergence

Multi-Model Mean (Future-Past)
250hPa Divergence

Multi-Model Mean (Future-Past)
250hPa Divergence

Multi-Model Mean (Future-Past)

Grey = Not statistically significant
Divergence (Future-Past)

$ci=5e^{-7}$

Multi-Model Mean (Future-Past)

Poleward - Not Poleward

$ci=5e^{-7}$

Divergent $\n$

Poleward - Not Poleward

$ci=0.2$

Grey = Not statistically significant
250hPa Divergence

Multi-Model Mean (Future-Past)

Divergent $v$

Grey = Not statistically significant
Divergent Meridional Wind Response

Poleward - Not Poleward
Divergent Meridional Wind Response

Asymmetry in divergent tropical Pacific circulation
Divergent Meridional Wind Response

Asymmetry in divergent tropical Pacific circulation

VS

EOF Index
Divergent Meridional Wind Response

Poleward - Not Poleward

VS

EOF Index

<math>\text{Divergent vs asymmetry}

\text{Not Poleward} \quad \text{Poleward}

= each CMIP5 model

\text{r} = -0.90 (-0.94, -0.84)
Weakening of the walker circulation and associated asymmetry in divergent V

Poleward shifting of the westerlies in the extratropical Pacific

Not Poleward

Poleward

$\star = \text{each CMIP5 model}$

$r = -0.90 (-0.94 , -0.84)$
Weakening of the walker circulation and associated asymmetry in divergent $V$ +

NO poleward shifting of the westerlies in the extratropical Pacific
NO weakening of the walker circulation and associated asymmetry in divergent V

NO poleward shifting of the westerlies in the extratropical pacific

Weakening asymmetry

= each CMIP5 model

Weakening of the walker circulation and associated asymmetry in divergent V

Poleward shifting of the westerlies in the extratropical pacific

\[ r = -0.90 (0.94, -0.34) \]
What’s driving what?
What’s driving what?

Tropics → Extra-tropics
What’s driving what?

Tropics \rightarrow \text{Extra-tropics}

Rossby Wave Source:

\[ RWS = -v \chi \cdot \nabla \zeta - \zeta D \]

Sardeshmukh and Hoskins (1988)
What’s driving what?

Tropics → Extra-tropics

Extra-tropics → Tropics
What’s driving what?

- Tropics → Extra-tropics
- Extra-tropics → Tropics
- Tropics ← Extra-tropics
What’s driving what?

Tropics → Extra-tropics

Extra-tropics → Tropics

Tropics ↔ Extra-tropics

Tropics ↔ Extra-tropics

?
Natural Variability in CESM
Natural Variability in CESM

- Inter-annual variability (DJF averages)
- Long pre-industrial control simulations
  - Coupled (1800 years)
  - Prescribed Climatological SSTs from coupled run (2600 years)

Available with the CESM Large Ensemble:
https://www2.cesm.ucar.edu/models/experiments/LENS
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Asymmetry in divergent tropical Pacific circulation

Regress fields onto the difference in divergent v between the blue box and the green box
Coupled

250hPa divergent $v$

700hPa $u$

$ci=0.2$

$ci=0.4$
Coupled

250hPa divergent v

700hPa u

Climatological SSTs

ci=0.2

ci=0.4
What’s driving what?

Tropics → Extra-tropics

Extra-tropics → Tropics

Tropics ↔ Extra-tropics

?
What’s driving what?

Tropics → Extra-tropics

Extra-tropics → Tropics

Tropics ↔ Extra-tropics

?
Natural Variability in CESM: Daily timescales

- 150y control run, prescribed climatological SSTs
- De-seasonalized daily data (DJF)

Asymmetry in divergent tropical Pacific circulation

Regress fields onto the difference in divergent v between the blue box and the green box
Natural Variability in CESM: Daily timescales

250hPa divergent v

700hPa u
Natural Variability in CESM: Daily timescales

250hPa divergent $v$

$ci=0.2$

700hPa $u$

$ci=0.4$

Lagged correlations with $vd$ index

![Graph showing lagged correlations with $vd$ index. The graph has a horizontal axis labeled 'Time (days)' ranging from -20 to 20, and a vertical axis labeled 'Correlation' ranging from -1.0 to 1.0. The graph includes two lines: one in blue labeled 'U' and one in red labeled 'Vd'.]
What’s driving what?

Tropics → Extra-tropics

Extra-tropics → Tropics

Tropics ↔ Extra-tropics
What’s driving what?

Tropics -> Extra-tropics

Extra-tropics -> Tropics

Tropics <-> Extra-tropics

Tropics <-> Extra-tropics
Conclusions

- Models exhibit considerable diversity in their extra-tropical zonal wind response to climate change during DJF.

- This is closely linked to the response in the divergent circulation in the tropical Pacific.

- Models that exhibit a weakening of the Walker circulation, exhibit a poleward shifting of the westerlies. Models that don’t exhibit a weakening of the Walker circulation, don’t exhibit a poleward shifting of the westerlies.

- What’s driving what?
  - Are we explaining diversity in the extra-tropical circulation response through the diversity in the tropical circulation \(\rightarrow\) need an understanding of the behavior of the tropics.
  - Are we explaining diversity in the tropical circulation response through the diversity in the extra-tropical circulation \(\rightarrow\) need an understanding of the behavior of the extra-tropics.
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models

West Pacific anomalies

u anomaly

0 20 40 60 80
Latitude

Multi-model Mean
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models

West Pacific anomalies

- Multi-model Mean
- Poleward Models
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models

West Pacific anomalies

- Multi-model Mean
- Poleward Models
- Not Poleward Models
700hPa zonal wind, Future - Past difference

Why this distinct behavior between these groups of models?
Coupled Climatological SSTs

250hPa divergent $v$

700hPa $u$

Coupled

Climatological SSTs

$\text{Cor} = -0.67$

$\text{Cor} = -0.67$

EOF projection

EOF projection

$m = -0.30$

$m = -0.22$
\[ \Delta P = \Delta E - \int_{p_s}^{0} \nabla \cdot (\Delta \vec{v} q) \, dp - \int_{p_s}^{0} \nabla \cdot (\vec{v} \Delta q) \, dp \]

**Change in circulation**

**Change in moisture**

**Precip and Budget**

- Blue: Not Poleward
- Red: Poleward

Dotted = sum of terms

**Moisture effect**

- Blue: Not Poleward
- Red: Poleward

**Circulation effect**

- Blue: Not Poleward
- Red: Poleward

**Circulation**

**SSTs**

**Precip**
West Pacific Jet Shifts

Distribution of jet shifts between pairs of 30 year samples taken at random from the piControl simulation (500y from CCSM4, 1000y from MPI-ESM-LR)
Why this difference?

\[ Q = - \left( \frac{P}{P_0} \right)^\kappa \omega \left( \frac{\partial \theta}{\partial p} \right) \]

Diabatic Heating

Vertical Advection
Why this difference?

\[ \Delta \omega = - \left( \frac{P}{P_o} \right)^{-\kappa} \left( \frac{\partial \theta}{\partial p} \right)_p^{-1} \Delta Q - \left( \frac{\partial \theta}{\partial P} \right)_p^{-1} \omega_p \Delta \left( \frac{\partial \theta}{\partial P} \right) + \text{Nonlinear} \]

- Change in Diabatic Heating
- Change in Stability
Full change in $\omega$

Component due to change in stability

Component due to change in $Q$
Past Climatological Vertical Velocity

Why this difference in the stability influence?

\[- \left( \frac{\partial \theta}{\partial P} \right)^{-1} \omega_p \Delta \left( \frac{\partial \theta}{\partial P} \right)\]

Future-Past Difference
Poleward - Not Poleward Models

Future-Past difference
Poleward - Not Poleward

Past Climatology
Poleward - Not Poleward

250hPa Divergence

250hPa Divergent v

700hPa zonal wind
Future-Past difference in divergent $v$

Past divergent $v$

(Future - Past) vs Past, divergent $v$

$r = -0.62 (-0.76, -0.45)$
<table>
<thead>
<tr>
<th>Poleward Models</th>
<th>Not Poleward Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMCC-CM</td>
<td>BNU-ESM</td>
</tr>
<tr>
<td>CMCC-CMS</td>
<td>CanESM2</td>
</tr>
<tr>
<td>CSIRO-Mk3-6-0</td>
<td>CCSM4</td>
</tr>
<tr>
<td>GISS-E2-R</td>
<td>CNRM-CM5</td>
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<tr>
<td>IPSL-CM5A-MR</td>
<td>FIO-ESM</td>
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<td>MIROC5</td>
<td>GFDL-ESM2G</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>GFDL-ESM2M</td>
</tr>
<tr>
<td>MPI-ESM-MR</td>
<td>inmcm4</td>
</tr>
<tr>
<td>MRI-CGCM3</td>
<td>NorESM1-ME</td>
</tr>
</tbody>
</table>
\[- \left( \frac{\partial \theta}{\partial P} \right)^{-1} \omega_p \Delta \left( \frac{\partial \theta}{\partial P} \right)\]
Vertically integrated diabatic heating
(top) past, (bottom) future-past
Precipitation (top) past, (bottom) future-past

Positive EOF1, past

Negative EOF1, past

Positive-Negative EOF1, past

Positive EOF1, difference

Negative EOF1, difference

Positive-Negative EOF1, difference
Stream function (top) Past, (bottom) Future-Past

Positive, past

Positive, future

Positive-Negative, past

Positive difference

Negative difference

Positive-Negative difference
Divergence (top) Past, (bottom) Future-past

Positive, past

Negative, past

Dif

Positive, difference

Negative, difference

Dif
SST response, anomalies from the tropical mean, Poleward models.
SST response, anomalies from the tropical mean, Poleward models.
Convective mass flux and vertical velocity

- Poleward, mass flux
- Poleward, vertical velocity
- Not poleward, mass flux
- Not poleward, vertical velocity
- Diff mass flux
- Diff, vertical velocity
Figure 10: For the average of four models positive models (MPI-ESM-LR, MPI-ESM-MR, MIROC5, MRI-CGCM3) comparing the AMIP climatology with the coupled climatology (top) sst anomaly from the tropical mean, (2nd) 500hPa omega, (3rd) 250hPa divergence, (4th) 700hPa zonal wind, (5th) 700hPa eddy zonal wind.
Figure 41: As Fig. 40 but for the positive and negative model composites (for comparison with Fig. 40)
Vertical Velocity

Multi-model mean past climatology

$ci = 0.008$
Multi-model mean past climatology

Vertical Velocity
Vertical Velocity
Vertical Velocity

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