Model Diversity in Future Predicted Circulation Change in the North Pacific

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Thanks to Clara Deser, Stephan Fueglistaler and Richard Seager for discussions
Dennis Shea and Adam Phillips for NCL tutoring
35 CMIP5 Models

DJF season

- PAST = 1979-2005 of historical
- FUTURE = 2070-2099 of RCP8.5
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)
West Pacific Jet Shifts
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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)
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)
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
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference
700hPa zonal wind, Future - Past difference

Poleward Models

Not Poleward Models

West Pacific anomalies

0 20 40 60 80
Latitude

u anomaly

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
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<thead>
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*Note: The table lists various climate models categorized as Poleward or Not Poleward Models.*
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Why this distinct behavior between these groups of models?
Possible Influences on the Extra-tropical Pacific

- Diabatically forced stationary waves from the tropics
- Orographically forced stationary waves
- Local extra-tropical diabatic forcing of the circulation
- Local changes in transient eddies
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250hPa Divergence and Divergent Meridional Wind

Divergence (Past)

Multi-Model Mean Past Climatologies

Divergence

Divergent v (Past)

Divergent v
250hPa Divergence and Divergent Meridional Wind

Divergence (Past)

Divergence (Future-Past)

Divergent v (Past)

Divergent v (Future-Past)
250hPa Divergence

Multi-Model Mean (Future-Past)

Divergence (Future-Past)

$ci=5e^{-7}$
**250hPa Divergence**

**Multi-Model Mean (Future-Past)**

- Divergence (Future-Past)
  - ci = 5e-7

- Poleward models
  - ci = 5e-7

- Not Poleward models
  - ci = 5e-7

Legend:
- Divergence (s⁻¹)
- Color scale:
  - -2e-06 to 2e-06
250hPa Divergence

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

Multi-Model Mean (Future-Past)

Grey = Not statistically significant
250hPa Divergence

Multi-Model Mean (Future-Past)

Divergent \( v \)

Poleward - Not Poleward

\( \text{Grey} = \text{Not statistically significant} \)
250hPa Divergence

Multi-Model Mean (Future-Past)

Divergent $v$

Grey = Not statistically significant
Divergent v in Blue Box

Poleward - Not Poleward
Divergent v in Blue Box

Poleward - Not Poleward

VS

EOF Index
Divergent $v$ in Blue Box

Poleward - Not Poleward

VS

EOF Index

Divergent $v$ vs EOF index

$\text{EOF index}$

$\text{Poleward}$

$\text{Not Poleward}$

$r = -0.86 (-0.92, -0.78)$

95% bootstrapping confidence interval
Regressions onto divergent $v$ in the natural variability of CCSM4
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Regressions onto divergent v in the natural variability of CCSM4
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A reasonable hypothesis is that the difference between the Poleward and the Not Poleward models arises from their different behaviors in the tropics.
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Multi-model mean past climatology

Vertical Velocity
Vertical Velocity

Multi-model mean past climatology

\( \text{ci} = 0.008 \)
Vertical Velocity

www.noaa.gov
Vertical Velocity

Future-Past

Pressure (hPa)

90E  180  90W  GM

ci=0.008

ci=0.004

Pacific Walker Circulation

www.noaa.gov
Vertical Velocity

www.noaa.gov
Why this difference?
Why this difference?

\[ Q = - \left( \frac{P}{P_o} \right)^\kappa \omega \left( \frac{\partial \theta}{\partial p} \right) \]
Why this difference?

$$Q = - \left( \frac{P}{P_o} \right)^\kappa \omega \left( \frac{\partial \theta}{\partial p} \right)$$

Diabatic Heating

Vertical Advection
Why this difference?

Increasing $\theta$
Why this difference?

Increasing $\theta$
Why this difference?

Increasing $\theta$
Why this difference?

Increasing $\theta$

Stability Influence
Why this difference?

Increasing $\theta$

Stability Influence
Why this difference?

Increasing $\theta$

Stability Influence

Redistribution of Diabatic Heating ($Q$)
Why this difference?

Increasing $\theta$

Stability Influence

Redistribution of Diabatic Heating (Q)
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 $\omega$
Full change in $\omega$

Component due to change in stability
Full change in $\omega$

Component due to change in stability

Component due to change in $Q$
Full change in $\omega$

Component due to change in stability

Component due to change in $Q$
Why this difference in the stability influence?

\[- \left( \frac{\partial \theta}{\partial P} \right)_p^{-1} \omega_p \Delta \left( \frac{\partial \theta}{\partial P} \right)\]
Past Climatological Vertical Velocity

Why this difference in the stability influence?

\[-\left(\frac{\partial \theta}{\partial P}\right)^{-1}_p \omega_p \Delta \left(\frac{\partial \theta}{\partial P}\right)\]
Past Climatological Vertical Velocity

Why this difference in the stability influence?

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

Future-Past Difference
Poleward - Not Poleward Models

Future-Past difference

Poleward - Not Poleward

$ci=5e-7$

250hPa Divergence
Poleward - Not Poleward Models

**Future-Past difference**
Poleward - Not Poleward

- $ci=5 \times 10^{-7}$

**Past Climatology**
Poleward - Not Poleward

- $ci=5 \times 10^{-7}$

**250hPa Divergence**

**250hPa Divergent $v$**
Poleward - Not Poleward Models

Future-Past difference
Past Climatology

250hPa Divergence
250hPa Divergent v
Poleward - Not Poleward Models

Future-Past difference
Poleward - Not Poleward

Past Climatology
Poleward - Not Poleward

250hPa
Divergence

250hPa
Divergent v

700hPa
zonal wind
Poleward - Not Poleward Models

Future-Past difference

Past Climatology

250hPa Divergence

250hPa Divergent v

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

Past divergent $v$

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

$r = -0.62 (-0.76, -0.45)$
Summary

- Models exhibit considerable diversity in their Future North Pacific circulation changes.

- This appears to be related to a difference in their response in the tropical Pacific.

- A model’s tropical circulation response seems to be related to its present day climatology.

- A model with greater climatological divergence in the western Pacific in the present day, exhibits a greater weakening of that divergence in the future and an associated poleward shifting of the westerlies.

- The “Not Poleward” Models are much more realistic when compared with ERA-Interim in quantities such as west pacific divergent v, location of the climatological jet.
Unanswered Questions

- What chain of events leads to such differences in the tropical circulation response? e.g. feedbacks with reorganization of diabatic heating, SST’s, clouds?

- What gives rise to these differences between the model climatologies? Looks likely to be associated with SST’s (magnitude of cold tongue bias)

- What is the relative importance of Rossby wave propagation and feedbacks involving transient eddies in giving rise to the extra-tropical circulation changes.
Extra Slides
Cor(TS, Precip)

Cor(TS, PR), CCSM4

Cor(TS, PR), MPI-ESM-LR
\[-\left(\frac{\partial \theta}{\partial P}\right)^{-1}_p \omega_p \Delta \left(\frac{\partial \theta}{\partial P}\right)\]
Past, u 250, poleward – not poleward
Past, u 250, not poleward - poleward
Vertically integrated diabatic heating (top) past, (bottom) future-past
Precipitation (top) past, (bottom) future-past
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.
SST anomalies from the tropical mean
Figure 40: 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)
Poleward

Not Poleward
Increase Static Stability

Poleward

Not Poleward
Increase Static Stability
Increase Static Stability
Increase Specific Humidity
Increase Static Stability
Increase Specific Humidity
Increase Static Stability
Increase Specific Humidity

Poleward

Not Poleward
Increase Static Stability
Increase Specific Humidity
Tropical divergence impacts on extra-tropical circulation in the present-day climate
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Future Changes - Poleward Models
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