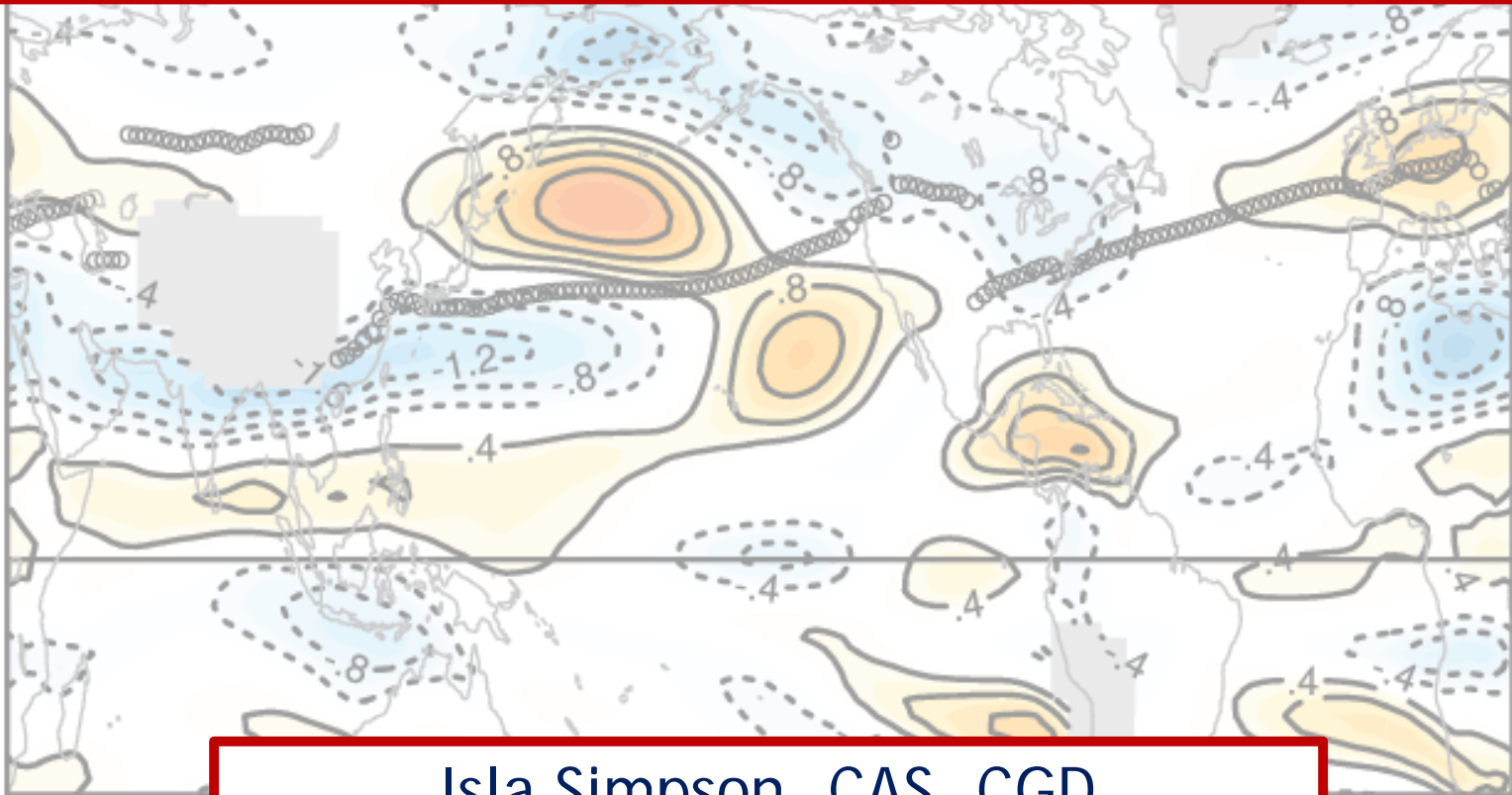


# Model Diversity in Future Predicted Pacific Circulation Change



Isla Simpson, CAS, CGD

Two circulation changes that are commonly considered to occur under global warming:

- (1) A poleward shifting of the mid-latitude westerlies
- (2) A weakening of the tropical divergent circulation

Two circulation changes that are commonly considered to occur under global warming:

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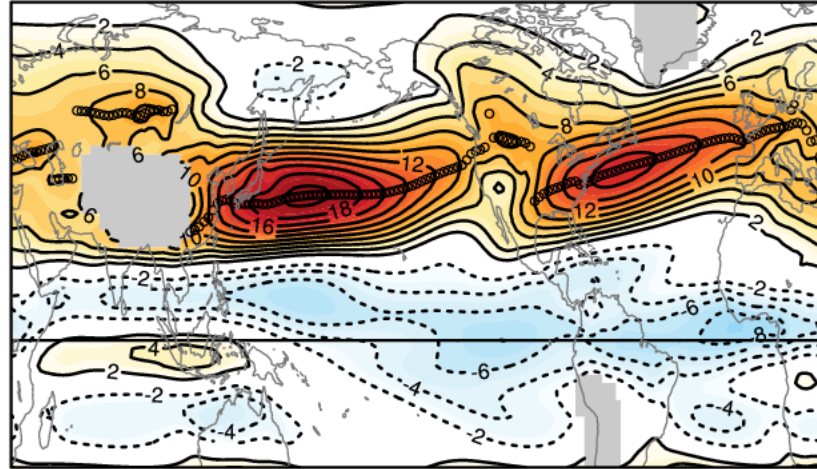
**Focus:** These circulation responses in the wintertime North Pacific (DJF) in the CMIP5 models.

(2070-2099) RCP8.5 - (1979-2005) historical

35 different models

# (1) A poleward shifting of the mid-latitude westerlies

Past →

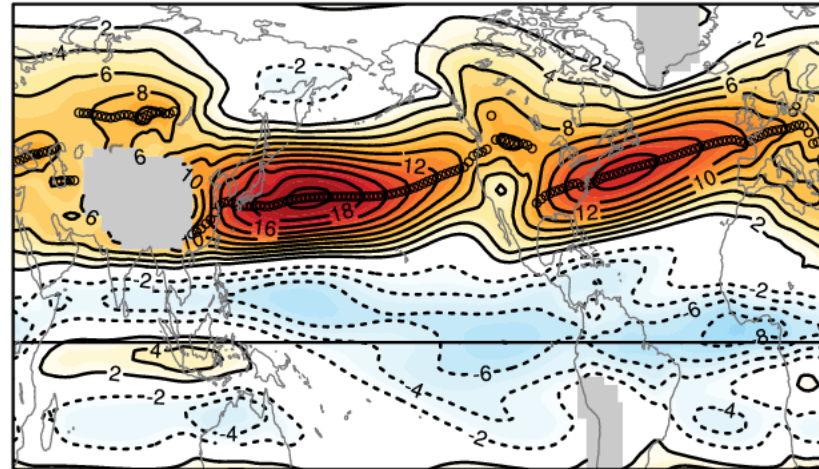


700hPa zonal wind  
Multi-model mean



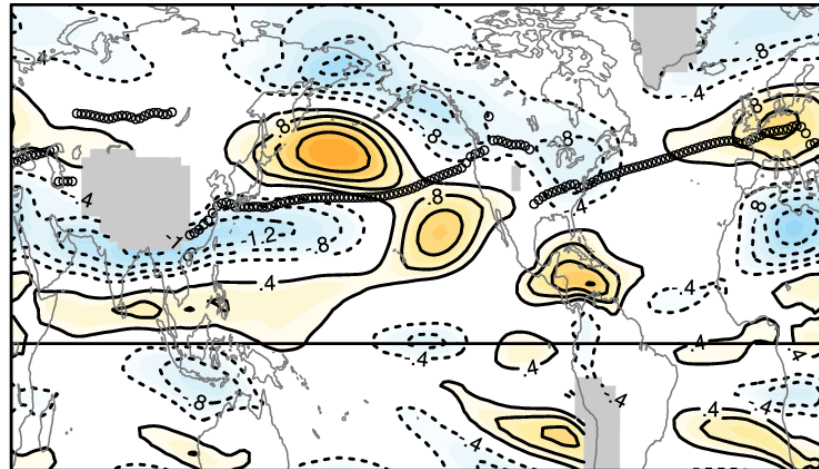
# (1) A poleward shifting of the mid-latitude westerlies

Past →

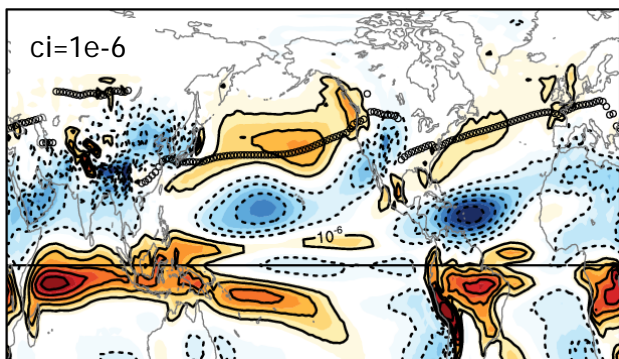


700hPa zonal wind  
Multi-model mean

Future-Past →

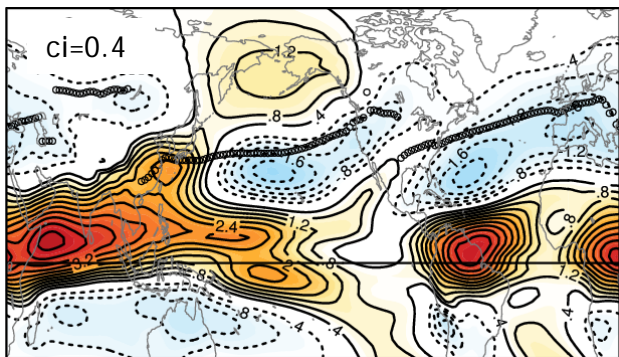


## (2) A weakening of the tropical divergent circulation



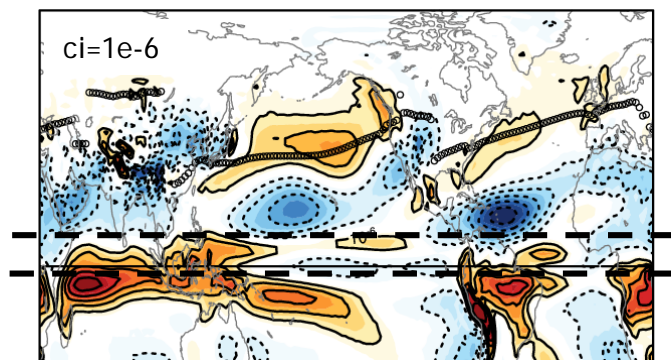
← 250hPa  
Divergence

Past Climatology



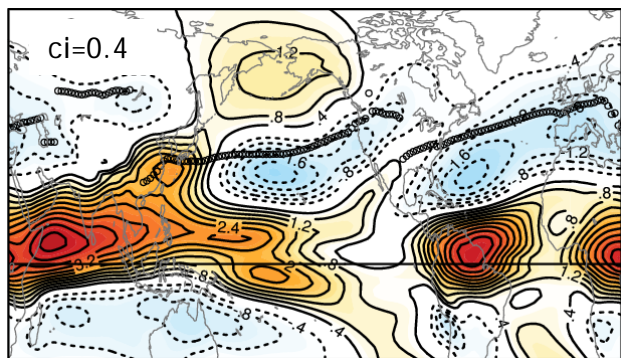
← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow

## (2) A weakening of the tropical divergent circulation



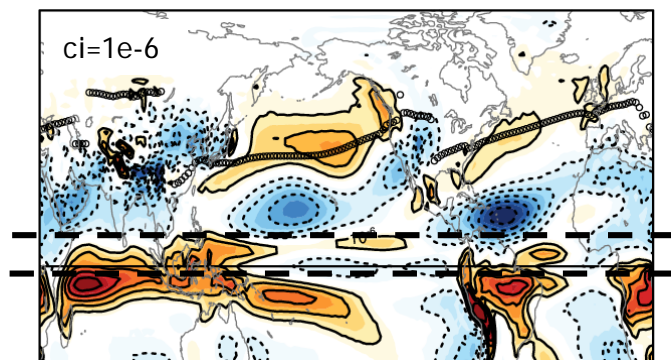
← 250hPa  
Divergence

Past Climatology



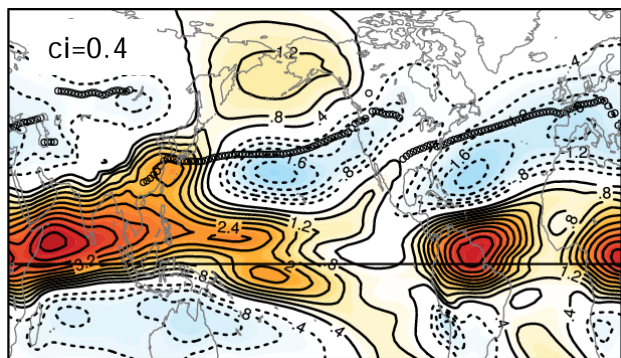
← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow

## (2) A weakening of the tropical divergent circulation

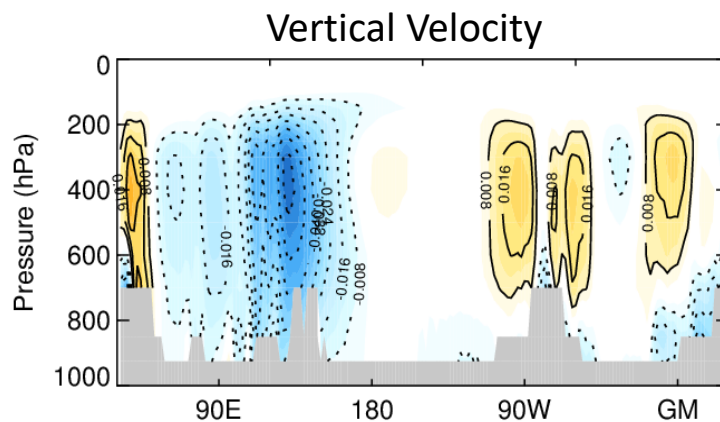


← 250hPa  
Divergence

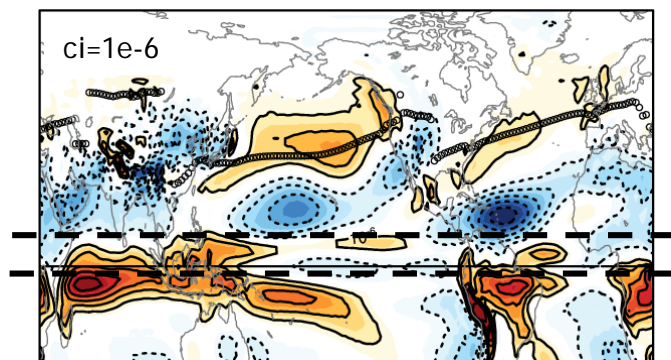
Past Climatology



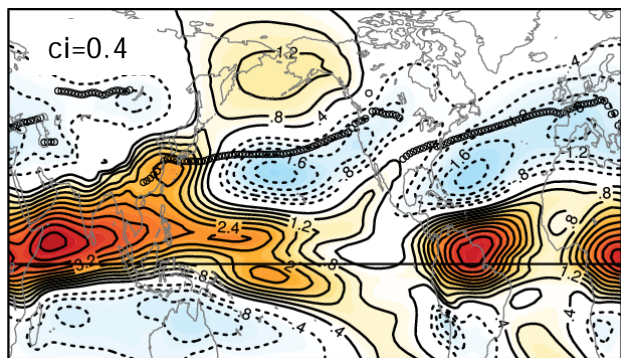
← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow



## (2) A weakening of the tropical divergent circulation

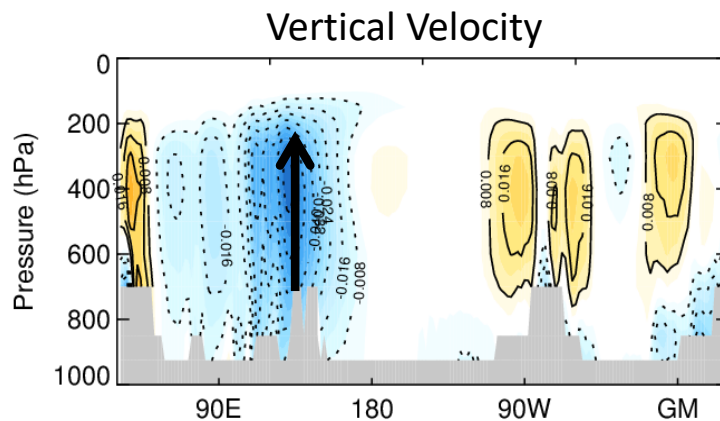


← 250hPa  
Divergence



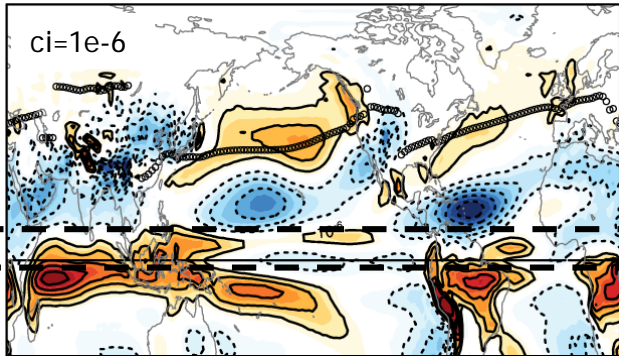
← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow

Past Climatology

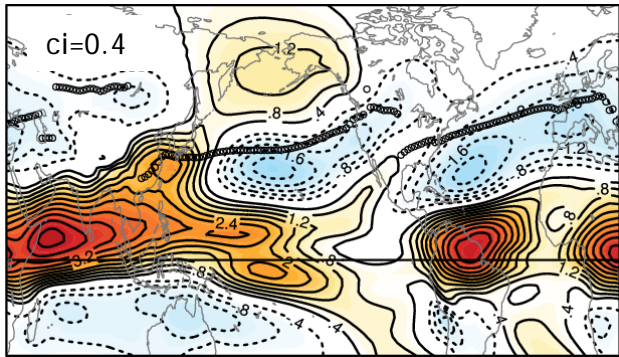




# (2) A weakening of the tropical divergent circulation

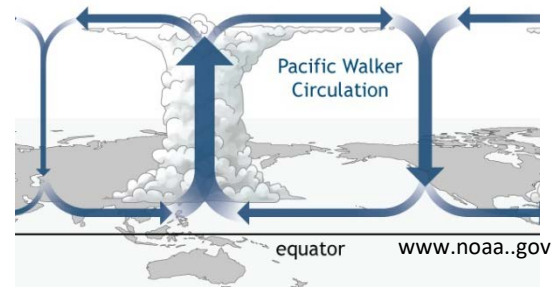
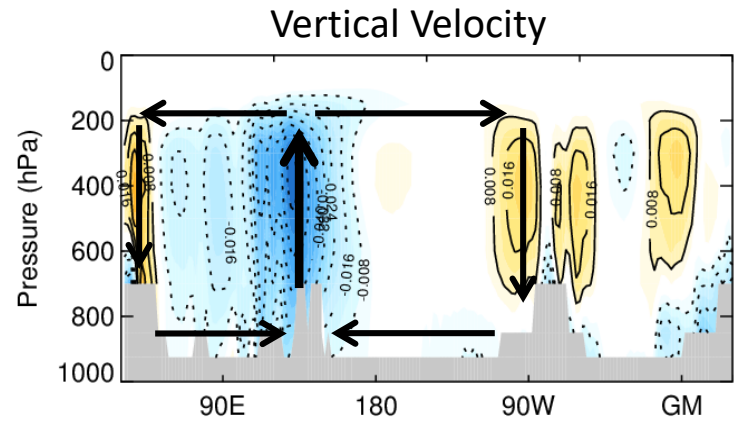


← 250hPa Divergence

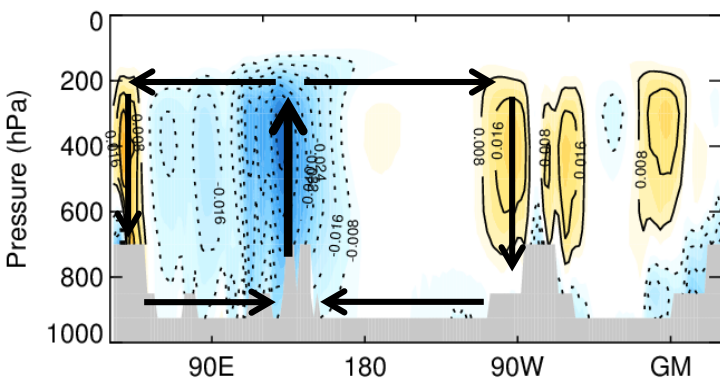
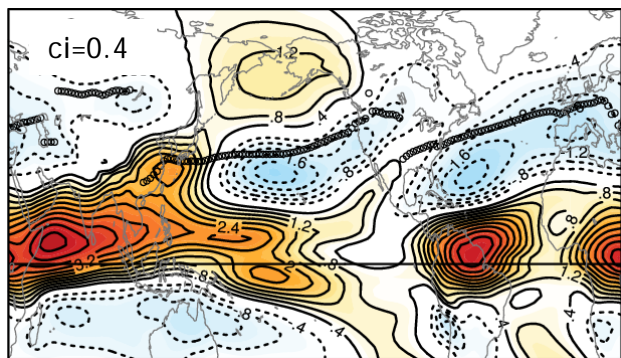
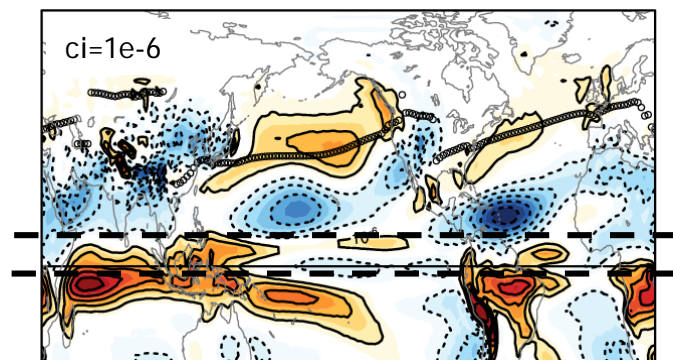


← 250hPa Meridional Component of the Divergent Flow

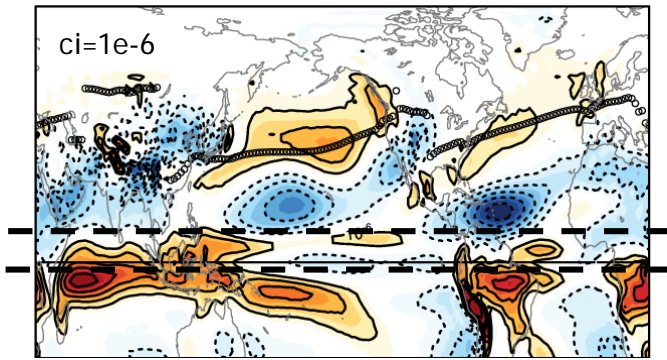
Past Climatology



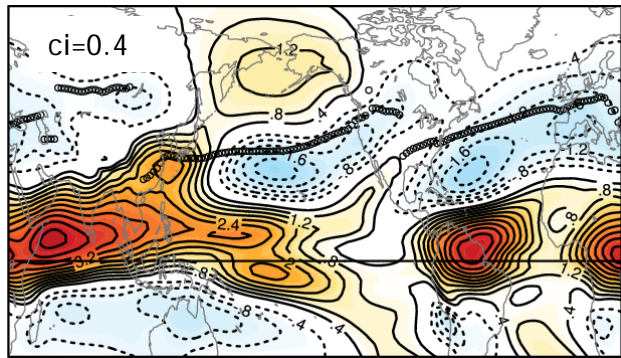
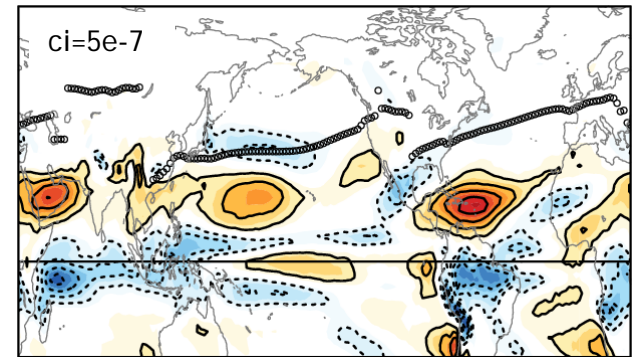
## (2) A weakening of the tropical divergent circulation



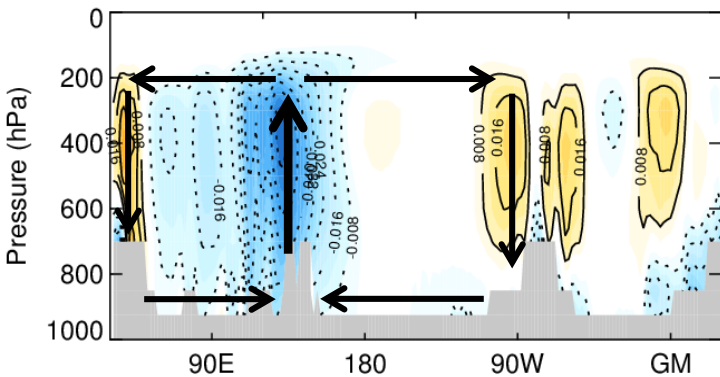
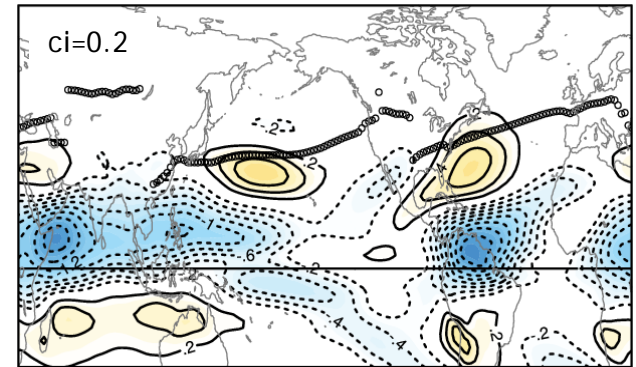
## (2) A weakening of the tropical divergent circulation



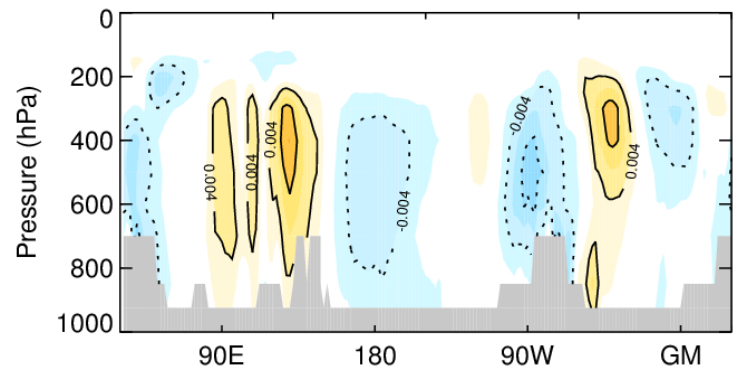
← 250hPa  
Divergence →



← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow →

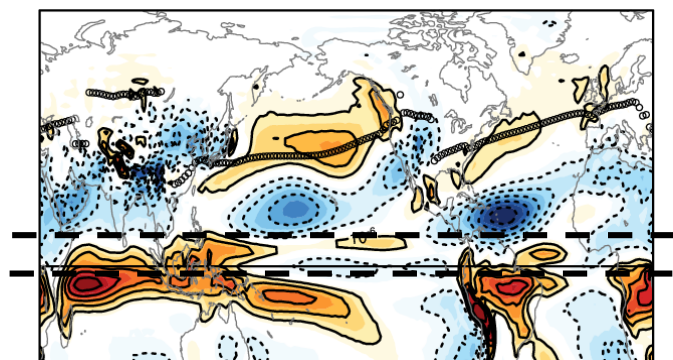


← Vertical  
Velocity  
(5S-10N) →

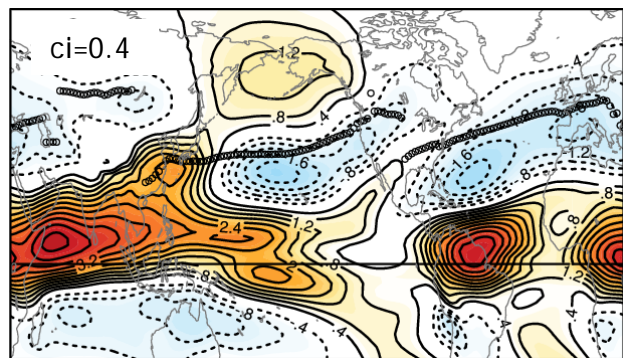
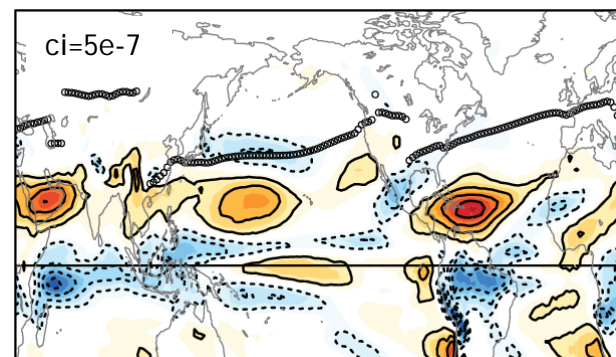




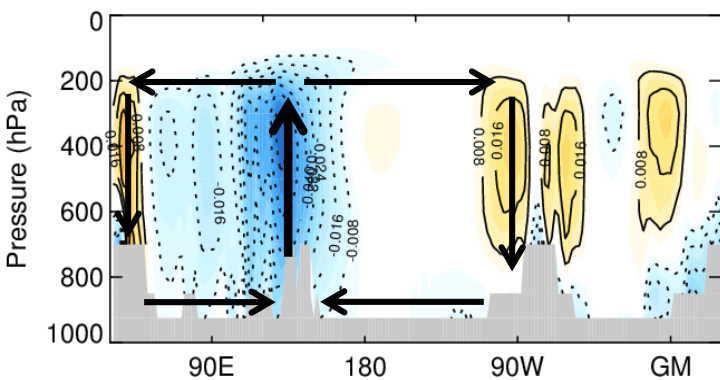
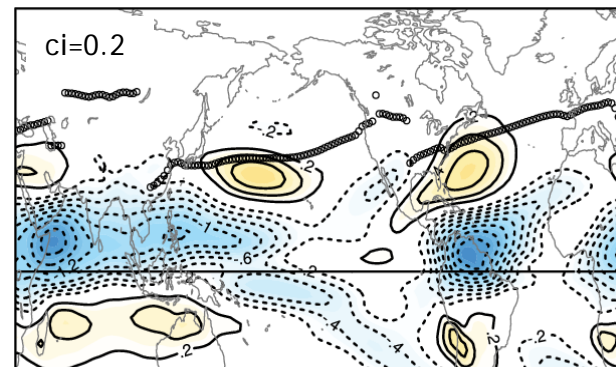
## (2) A weakening of the tropical divergent circulation



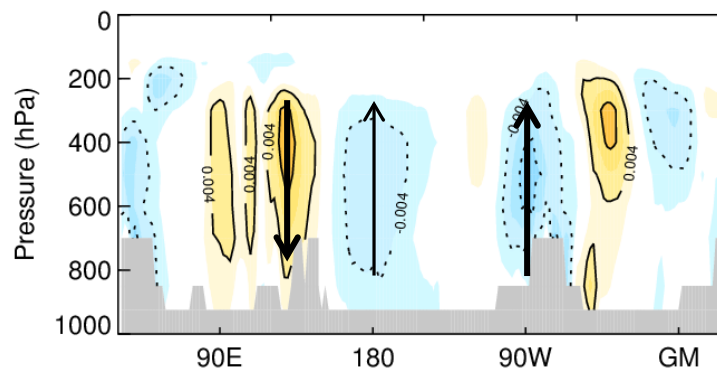
← 250hPa  
Divergence →



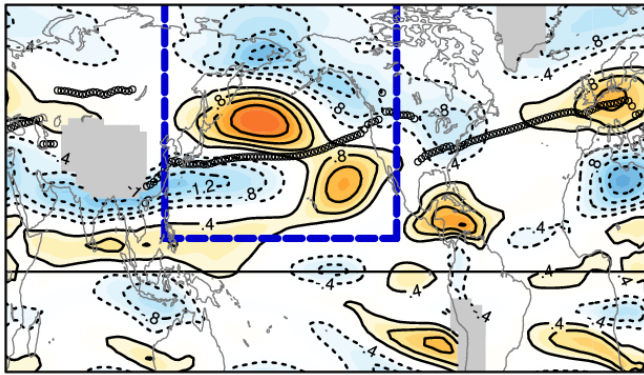
← 250hPa  
Meridional  
Component  
of the  
Divergent  
Flow →



← Vertical  
Velocity  
(5S-10N) →

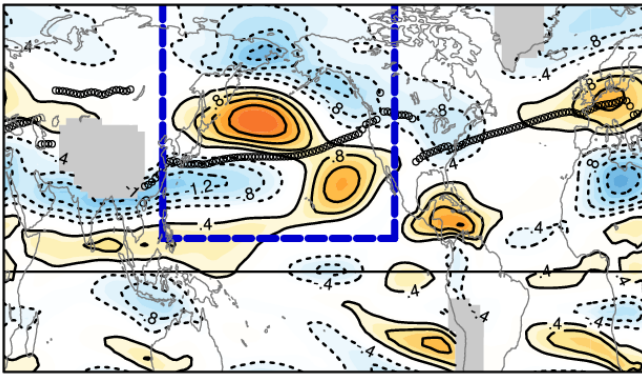


BUT, there is considerable spread among the models in both these aspects, and they are connected.

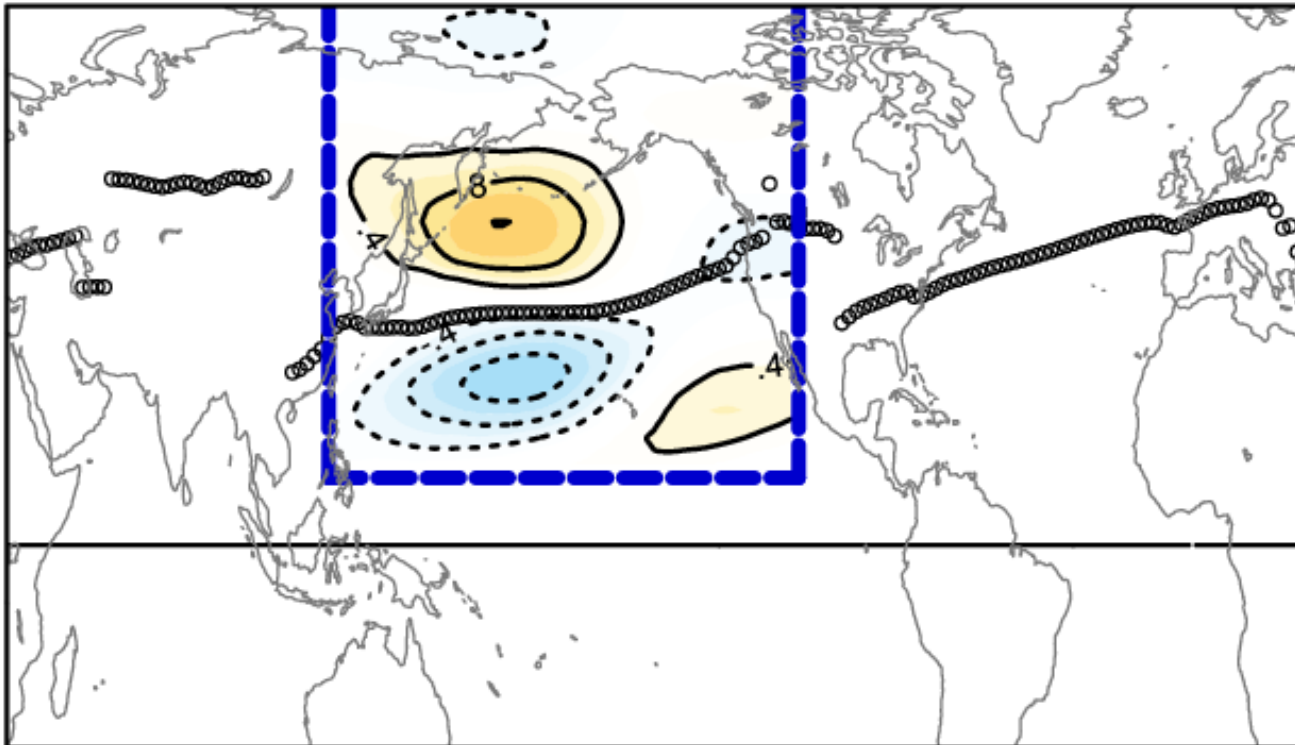


EOF analysis (across models)  
of zonal wind response

# EOF analysis (across models) of zonal wind response



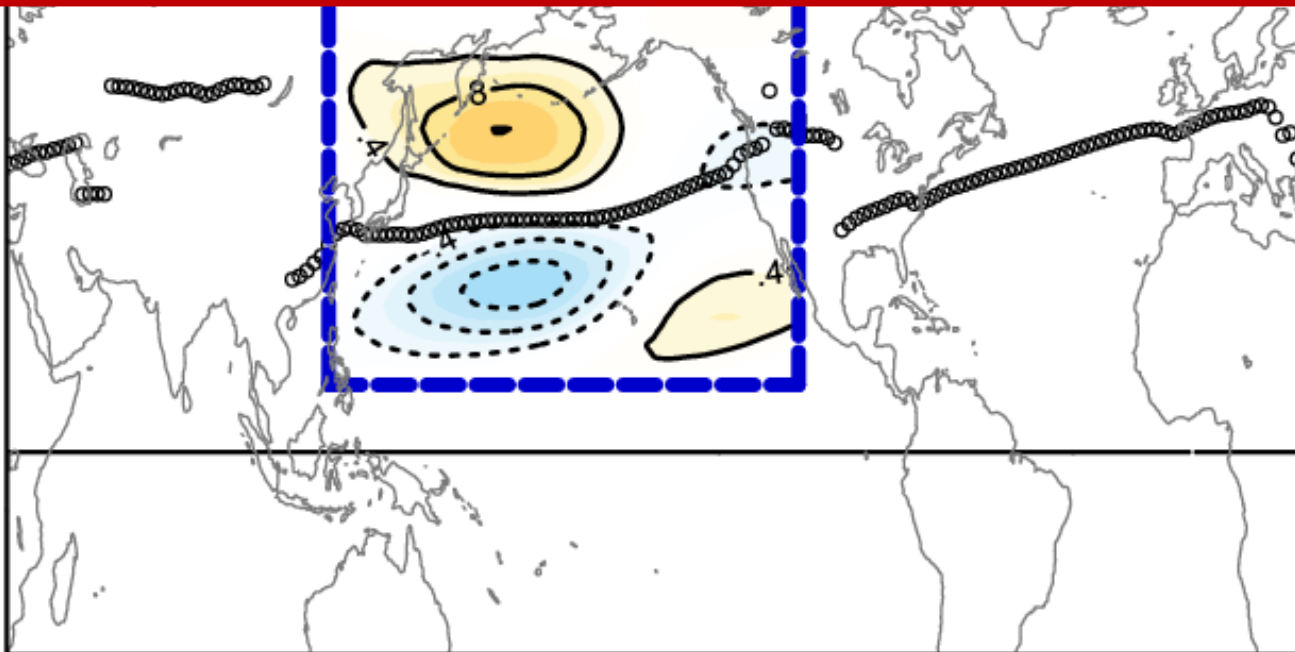
EOF1, 37.5% of variance explained



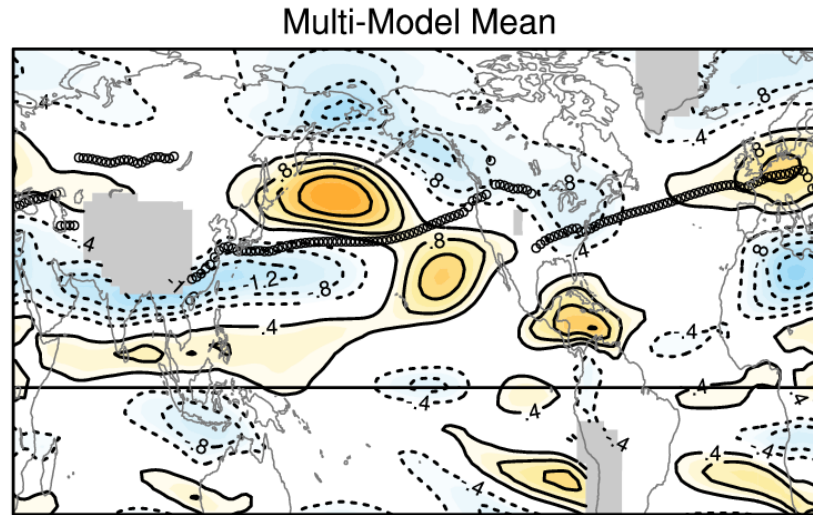
Use the EOF Index as a measure of a models behaviour in the extra-tropical west Pacific

25% most positive EOF1 = Poleward Models

25% most negative EOF1 = Not Poleward Models  
(9 models in each group)



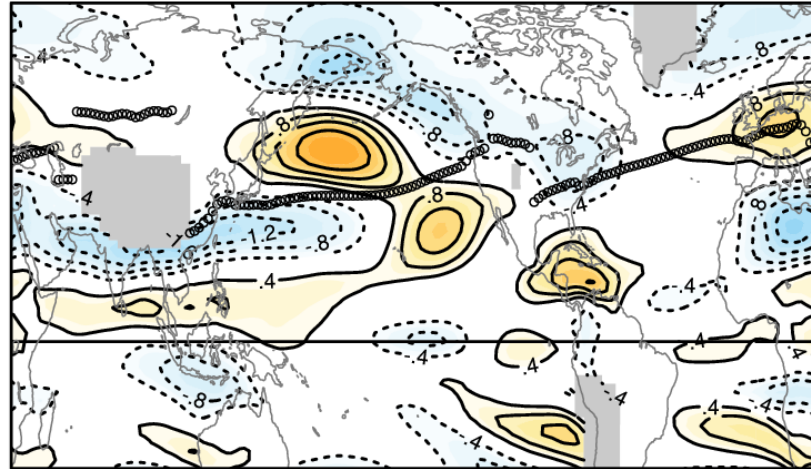
# 700hPa zonal wind, Future - Past difference



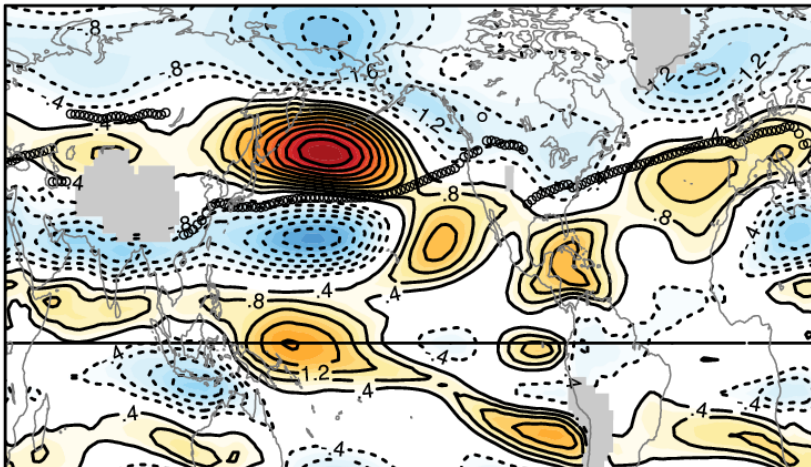


# 700hPa zonal wind, Future - Past difference

Multi-Model Mean

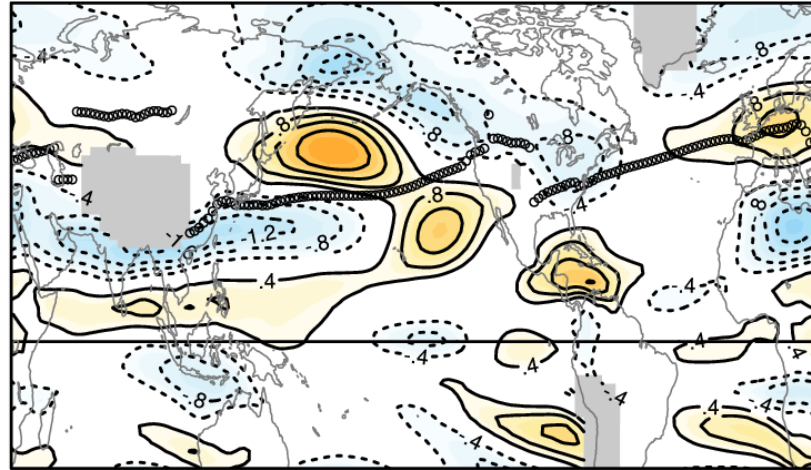


Poleward Models

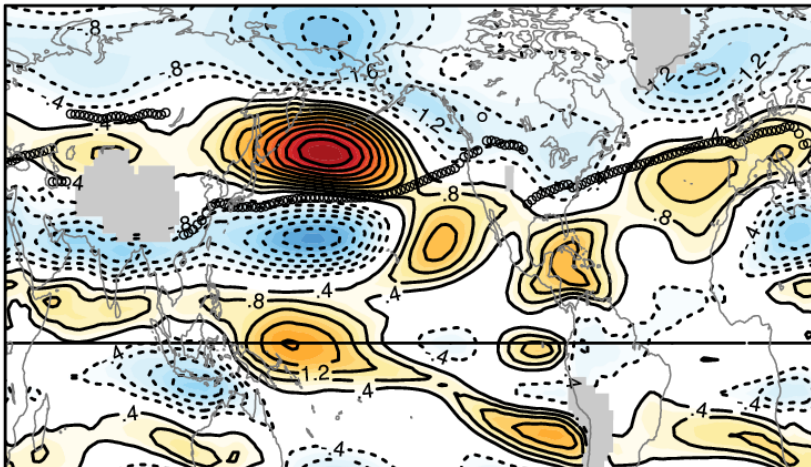


# 700hPa zonal wind, Future - Past difference

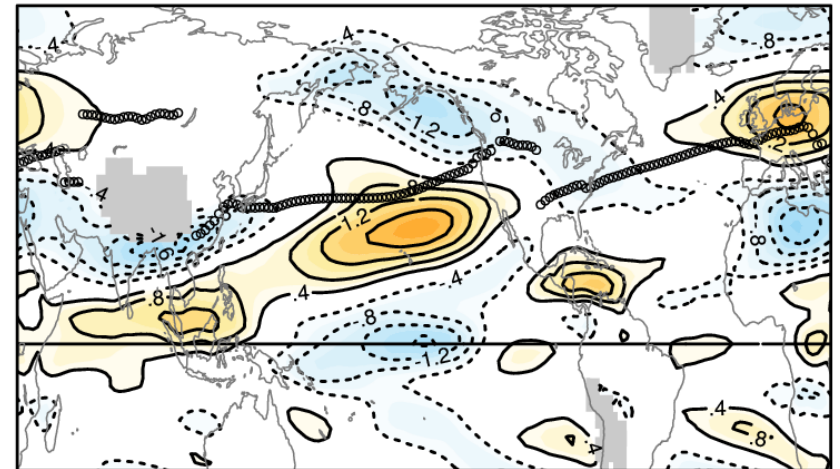
Multi-Model Mean



Poleward Models

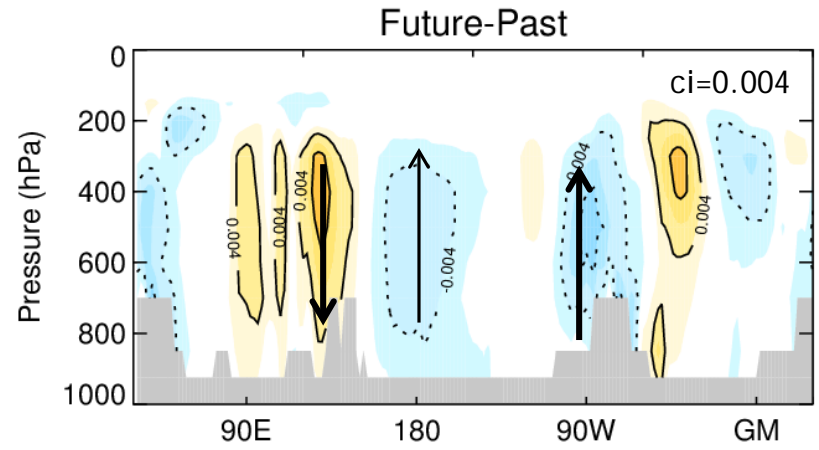
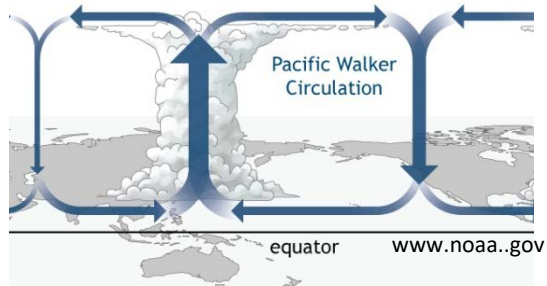


Not Poleward Models

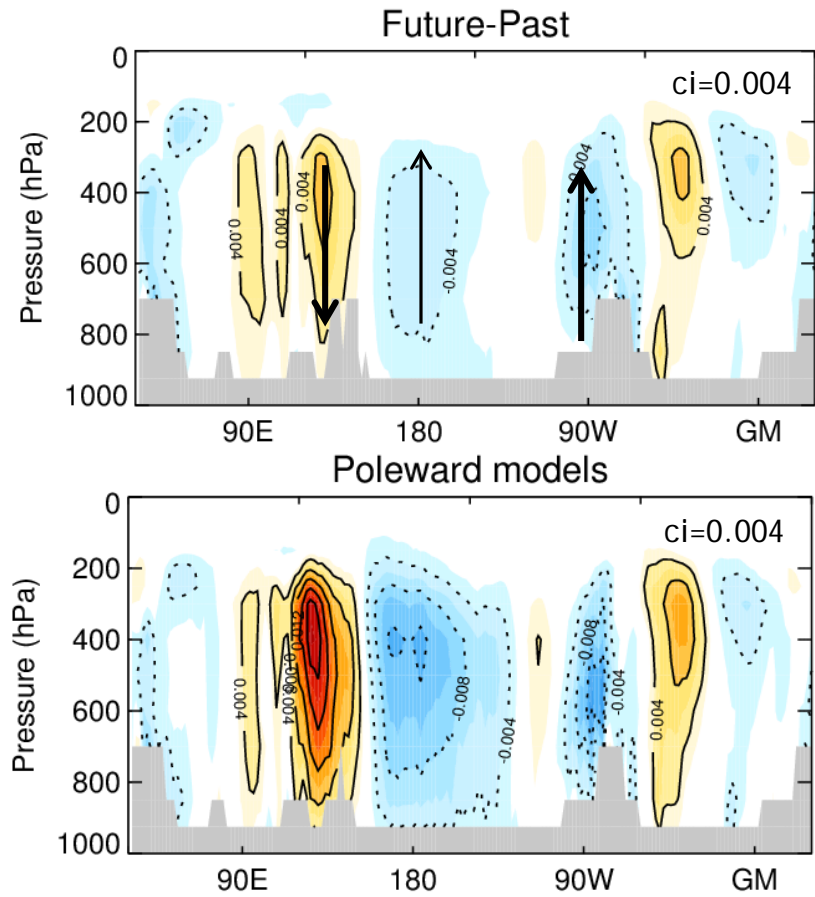
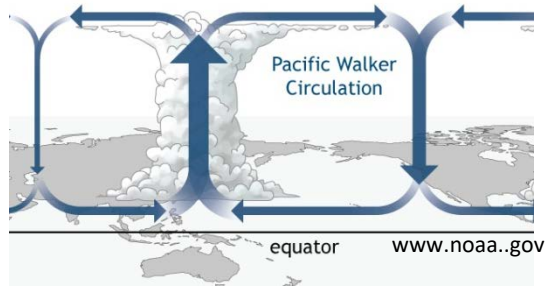




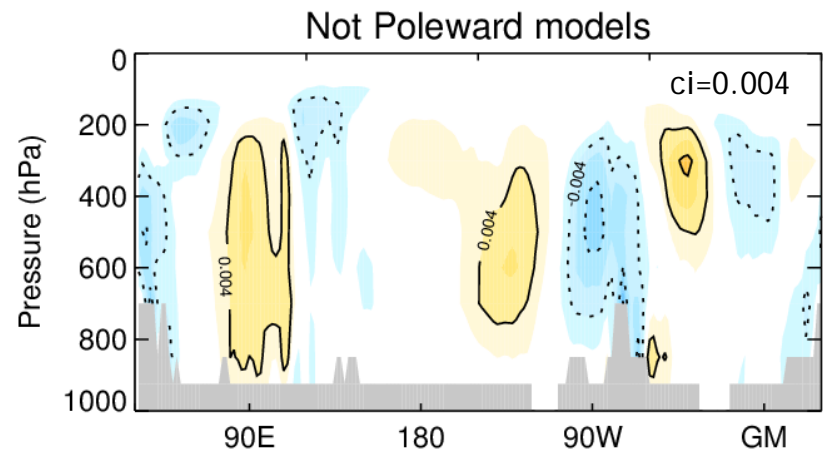
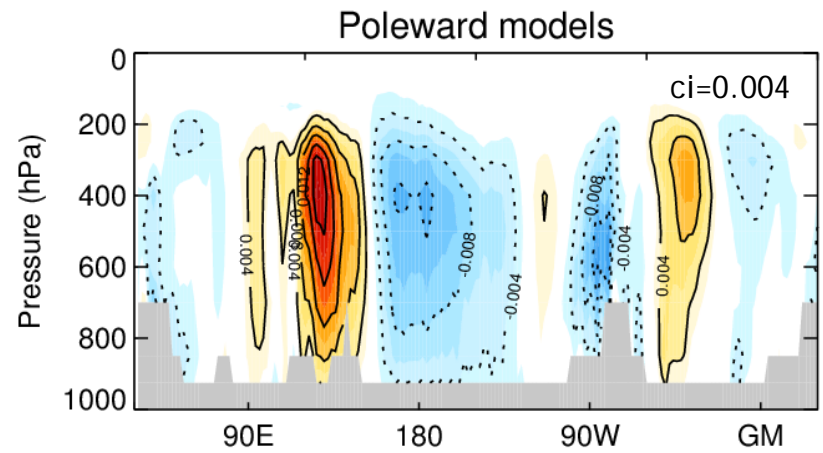
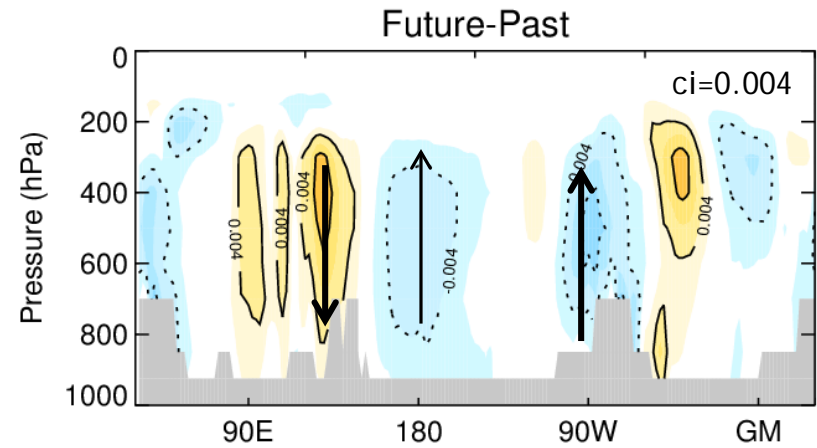
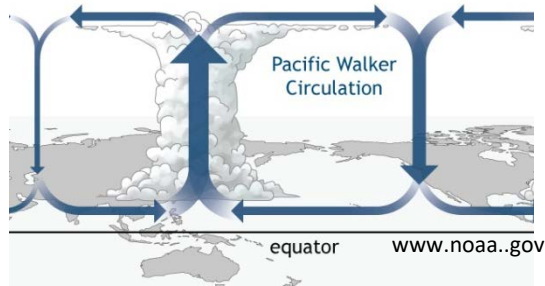
# Walker Circulation



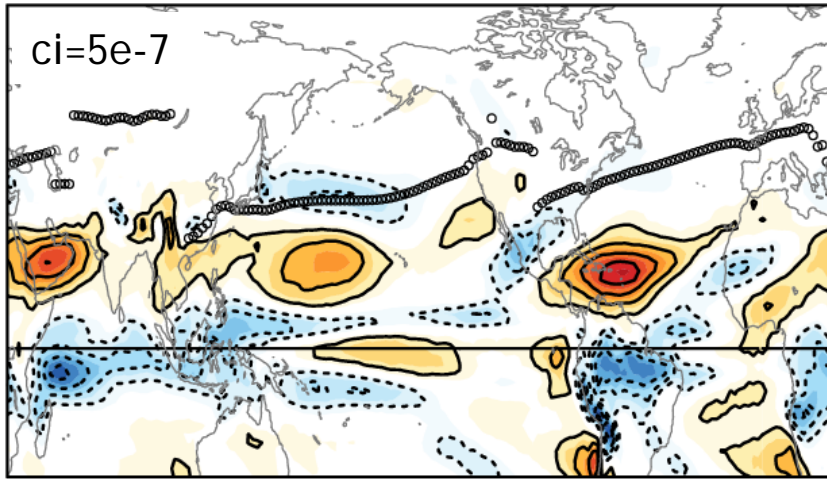
# Walker Circulation



# Walker Circulation

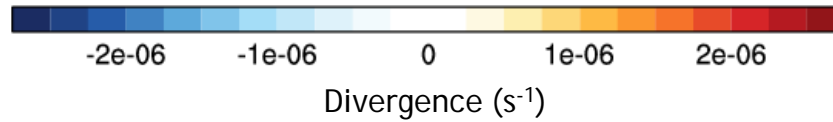


Divergence (Future-Past)

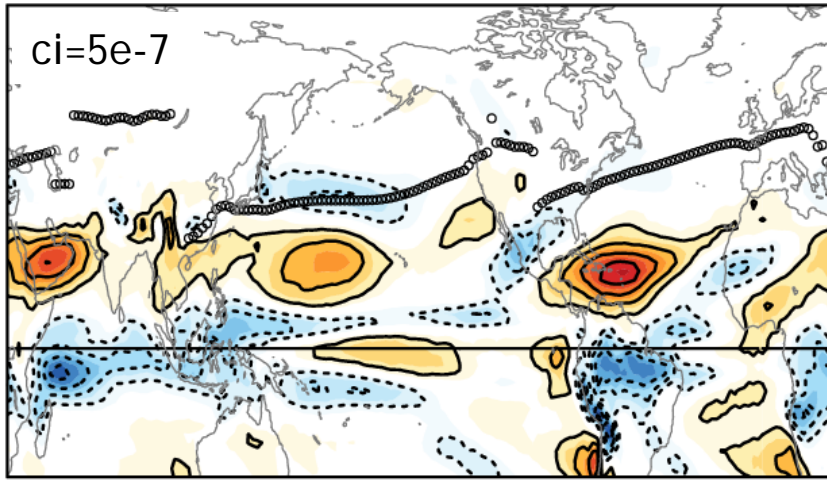


250hPa Divergence

Multi-Model Mean  
(Future-Past)



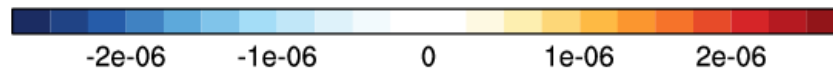
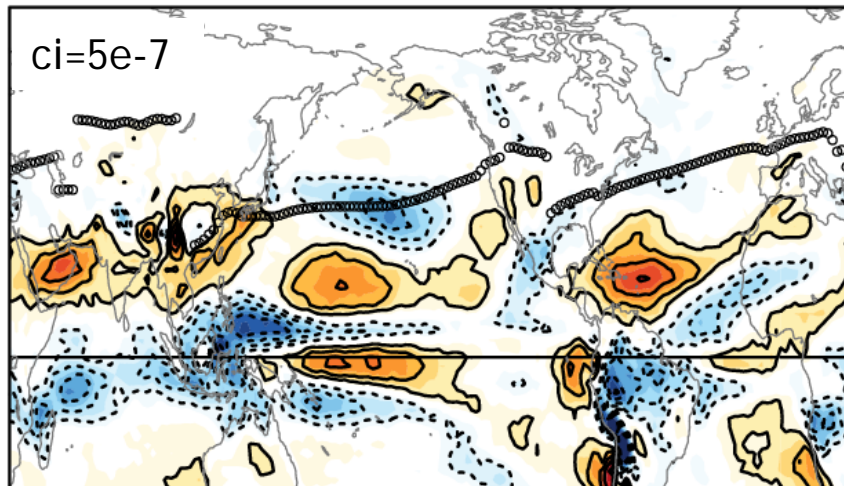
Divergence (Future-Past)



250hPa Divergence

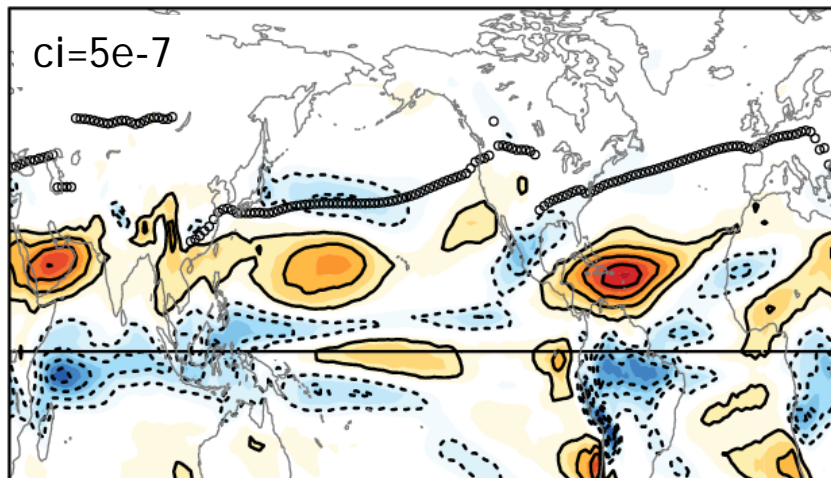
Multi-Model Mean  
(Future-Past)

Poleward models



Divergence ( $\text{s}^{-1}$ )

Divergence (Future-Past)

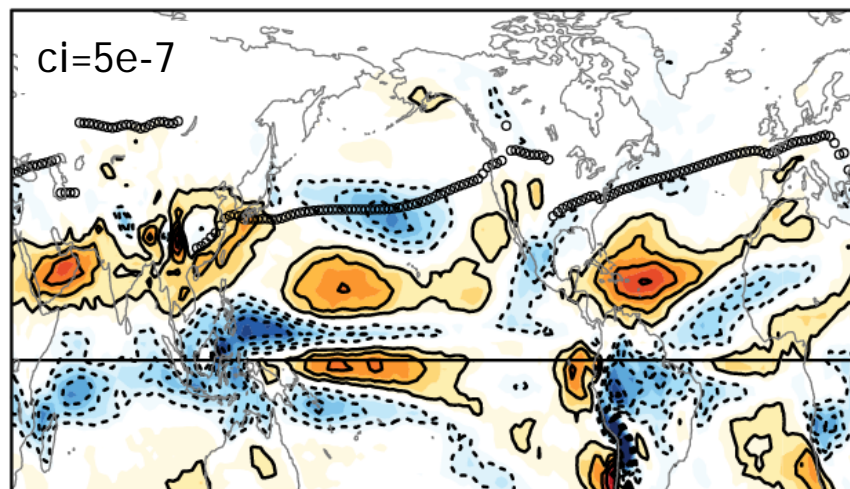


# 250hPa Divergence

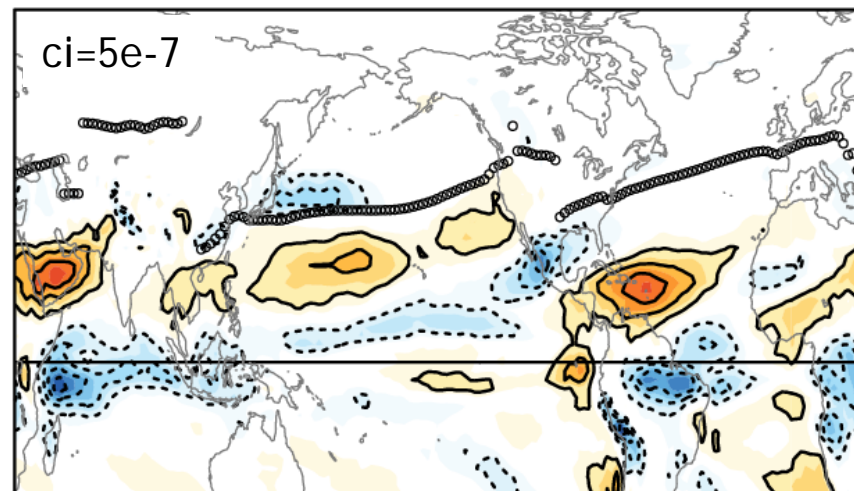
Multi-Model Mean  
(Future-Past)



Poleward models



Not Poleward models

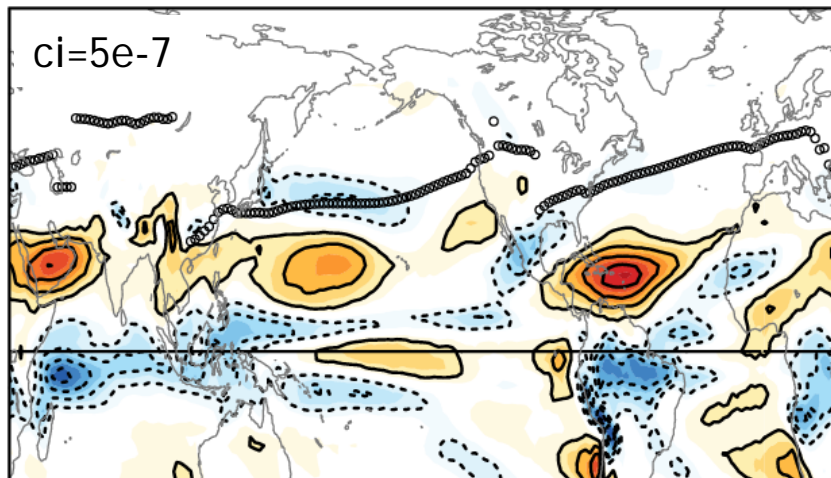


-2e-06   -1e-06   0   1e-06   2e-06

Divergence (s<sup>-1</sup>)



Divergence (Future-Past)

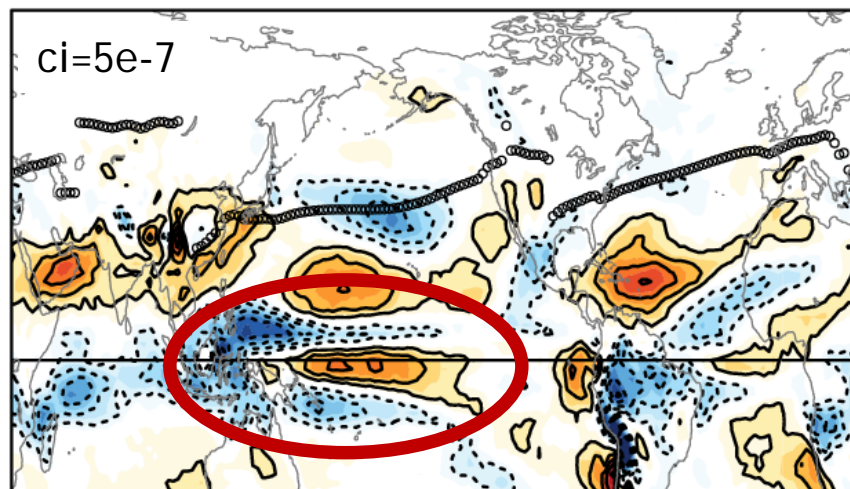


# 250hPa Divergence

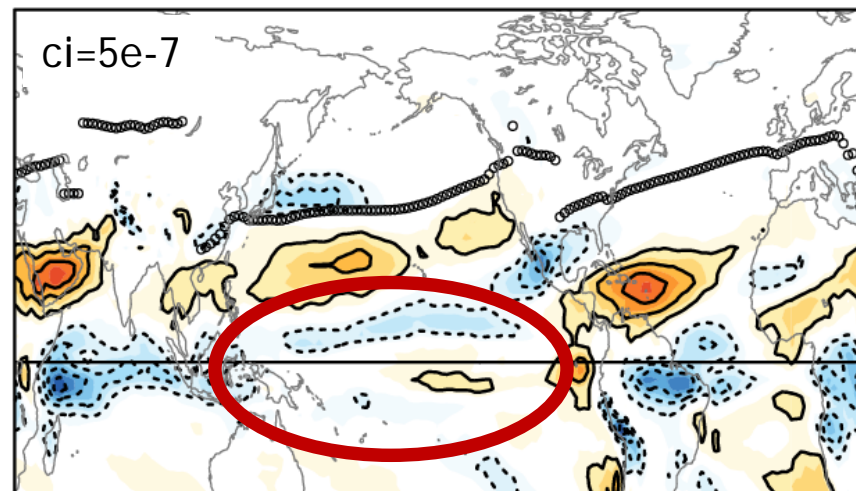
Multi-Model Mean  
(Future-Past)



Poleward models



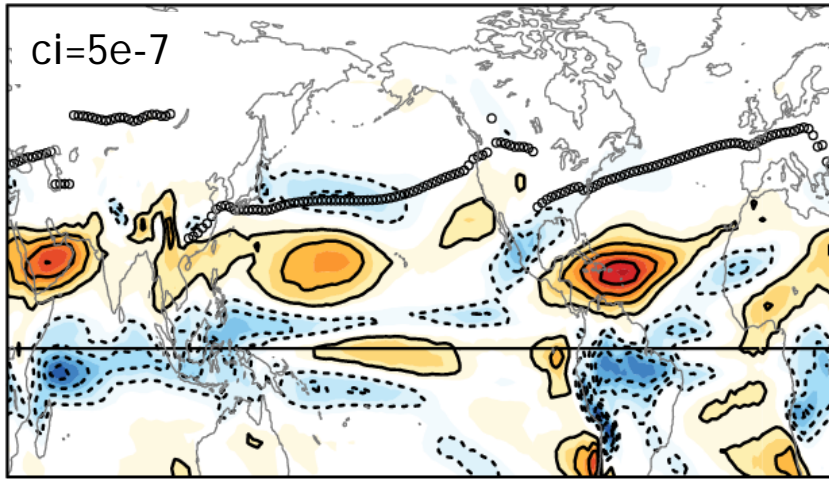
Not Poleward models



-2e-06   -1e-06   0   1e-06   2e-06

Divergence (s<sup>-1</sup>)

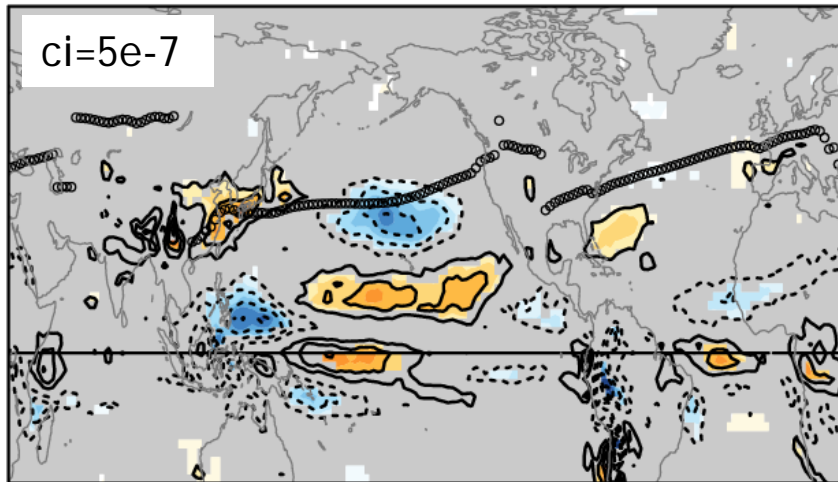
Divergence (Future-Past)



## 250hPa Divergence

Multi-Model Mean  
(Future-Past)

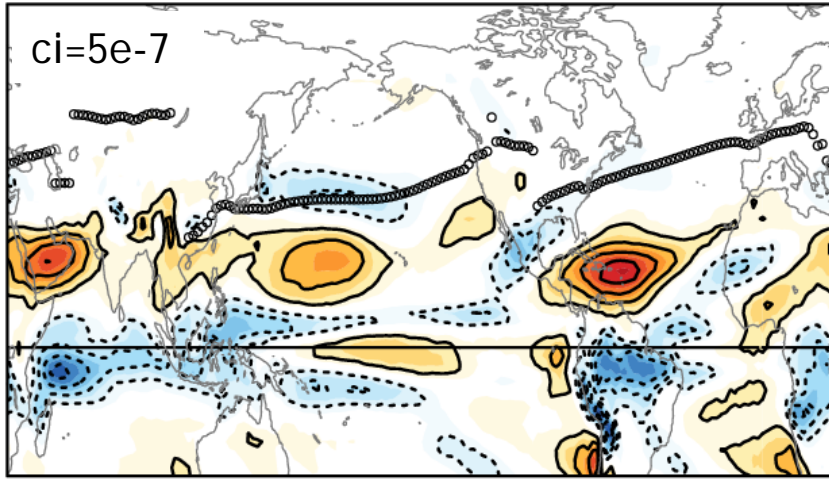
Poleward - Not Poleward



Grey = Not statistically significant



Divergence (Future-Past)

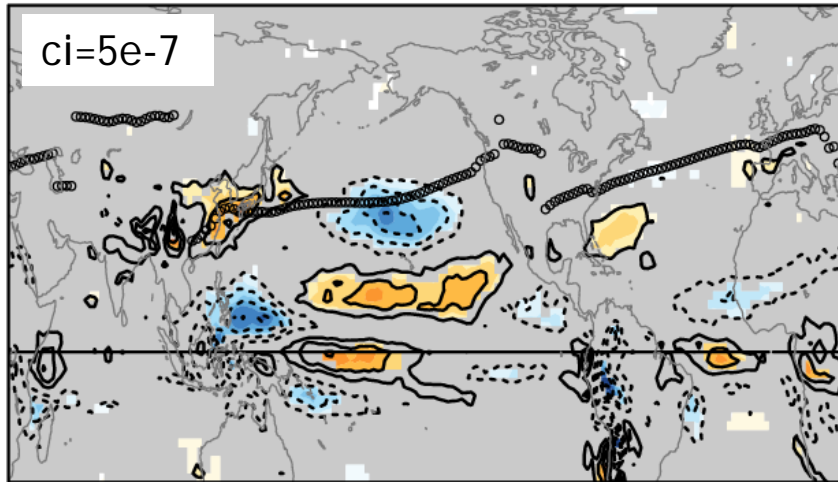


# 250hPa Divergence

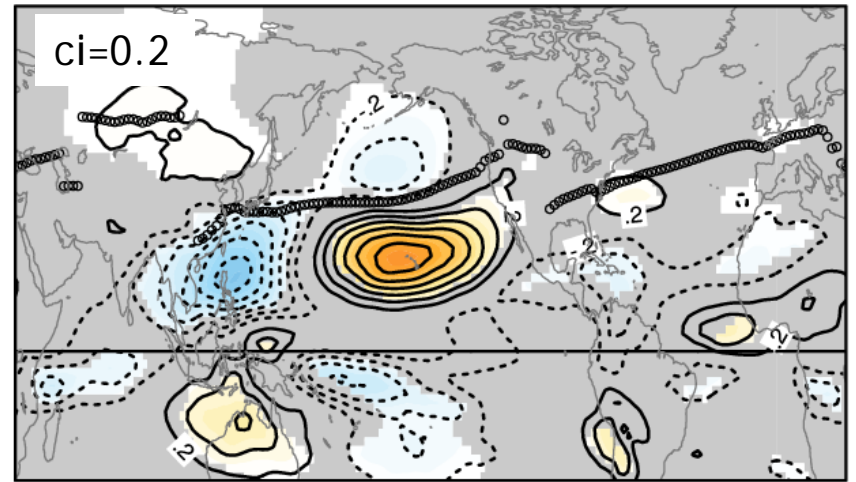
Multi-Model Mean  
(Future-Past)

Divergent v

Poleward - Not Poleward

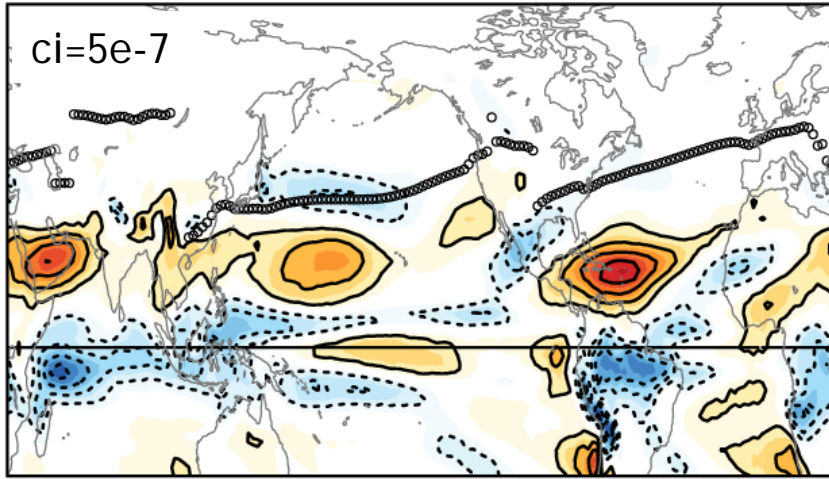


Poleward - Not Poleward



Grey = Not statistically significant

Divergence (Future-Past)

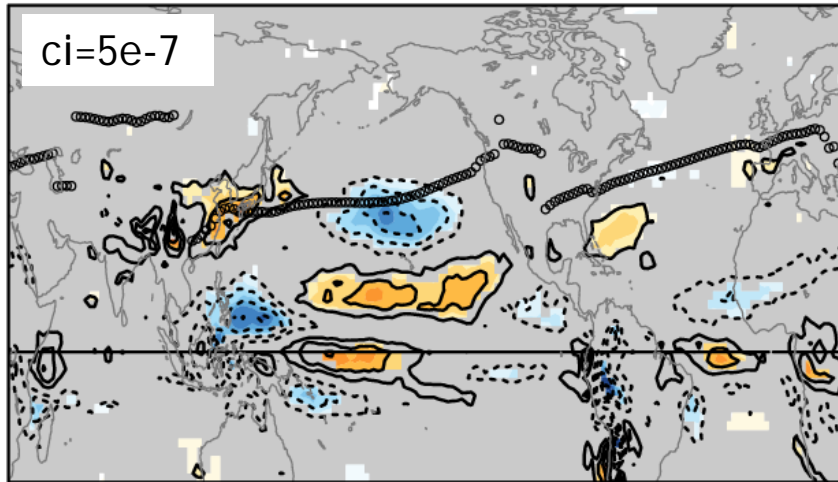


# 250hPa Divergence

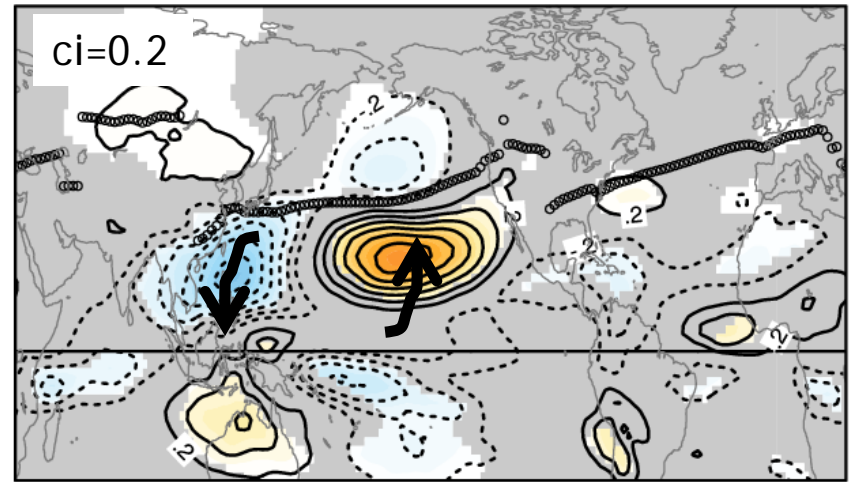
Multi-Model Mean  
(Future-Past)

Divergent v

Poleward - Not Poleward



Poleward - Not Poleward

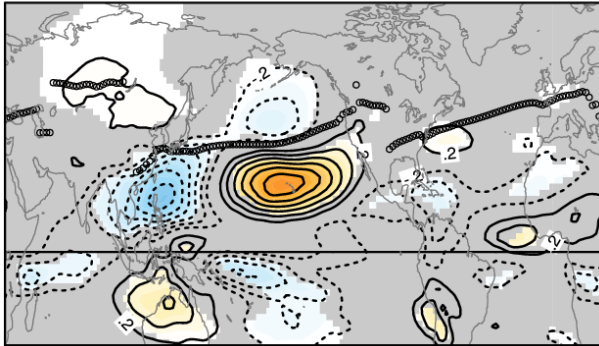


Grey = Not statistically significant

There is a very strong connection between the poleward shifting of the westerlies in the extra-tropics and the weakening of the divergent circulation in the tropics.

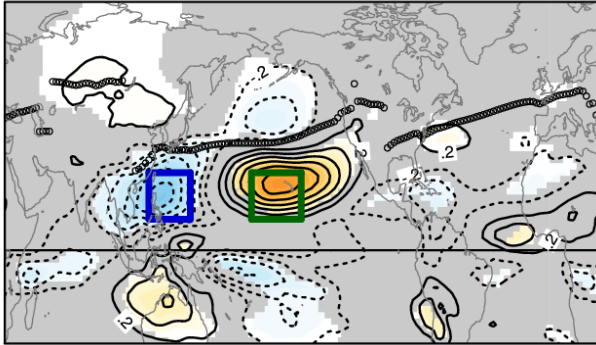
# Divergent Meridional Wind Response

Poleward - Not Poleward



# Divergent Meridional Wind Response

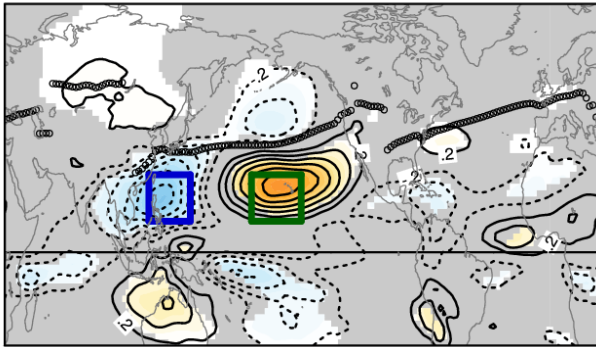
Poleward - Not Poleward



 -  Asymmetry in divergent tropical Pacific circulation

# Divergent Meridional Wind Response

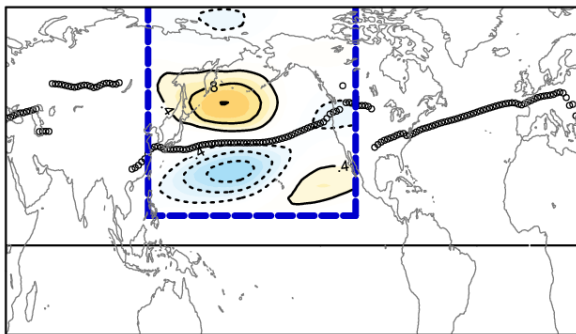
Poleward - Not Poleward



Asymmetry in divergent tropical Pacific circulation

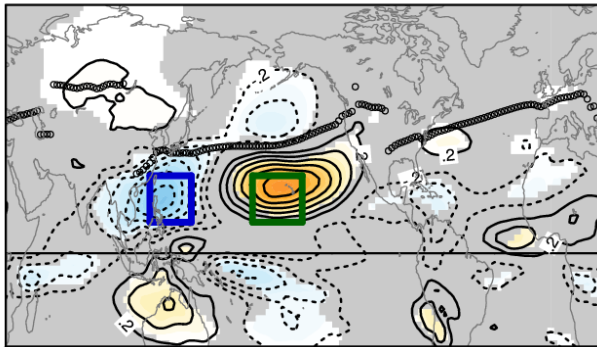
VS

EOF Index



# Divergent Meridional Wind Response

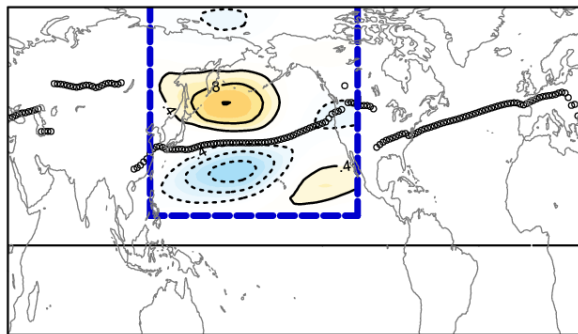
Poleward - Not Poleward



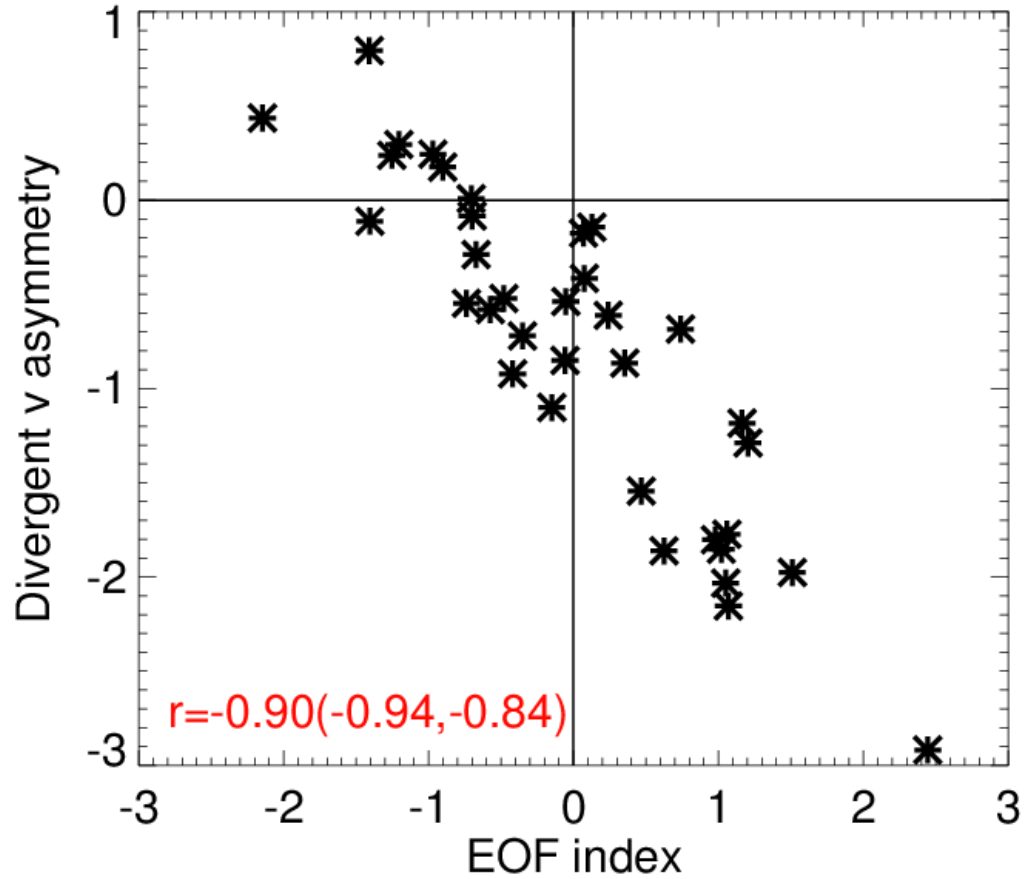
VS

Weakening  
asymmetry

EOF Index



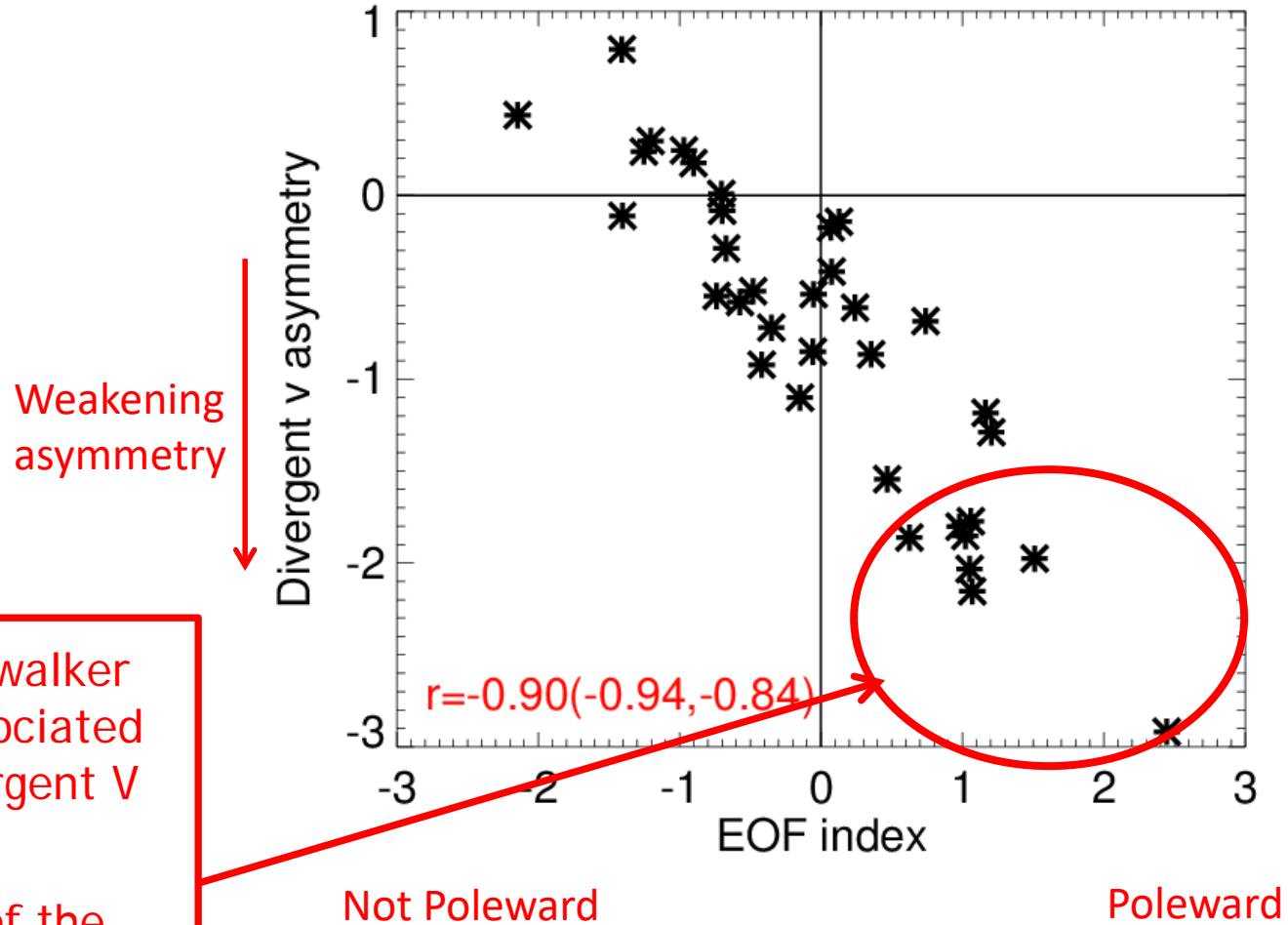
\* = each CMIP5 model



Not Poleward

Poleward

\* = each CMIP5 model



Weakening of the walker circulation and associated asymmetry in divergent V

+

Poleward shifting of the westerlies in the extra-tropical pacific



NO weakening of the walker circulation and associated asymmetry in divergent V

+

NO poleward shifting of the westerlies in the extra-tropical pacific

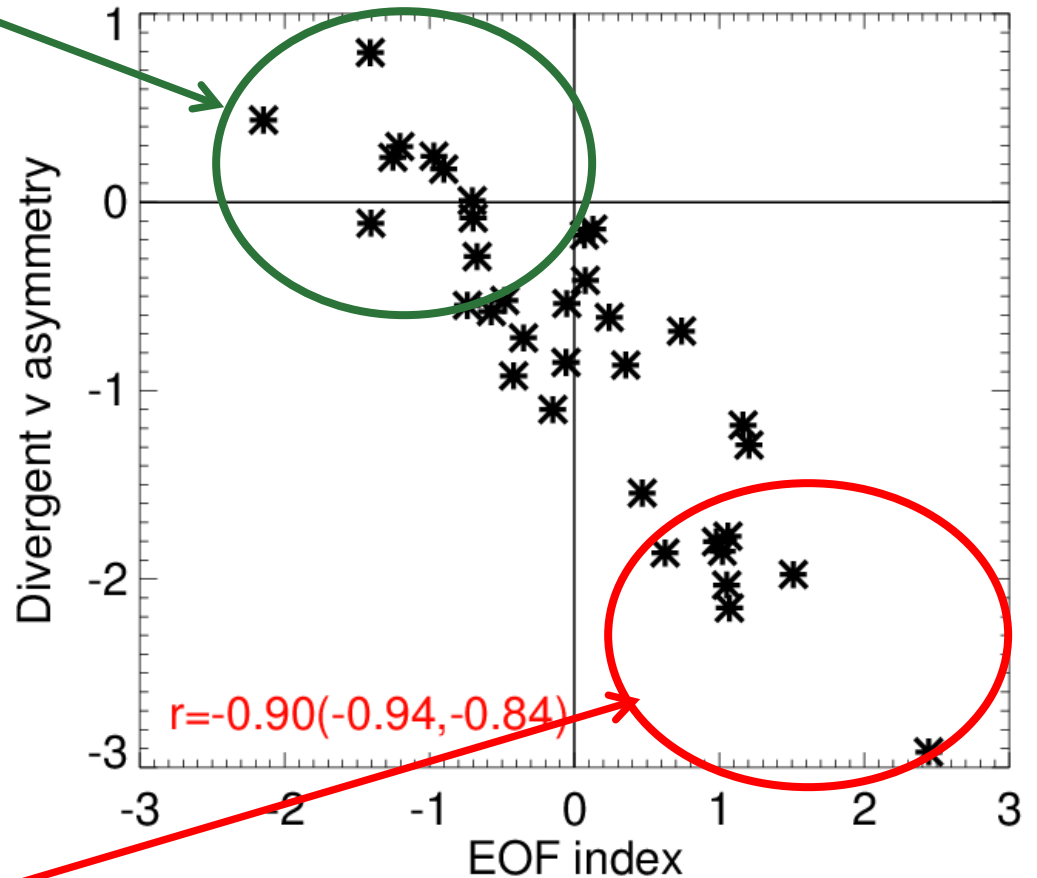
Weakening asymmetry

Weakening of the walker circulation and associated asymmetry in divergent V

+

Poleward shifting of the westerlies in the extra-tropical pacific

\* = each CMIP5 model

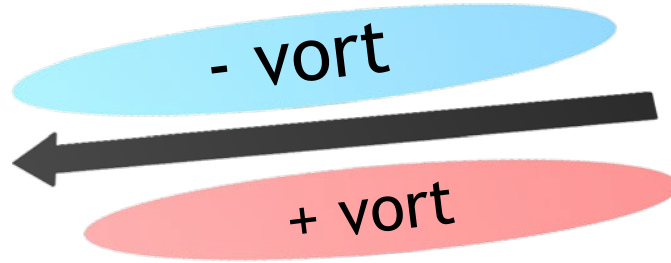
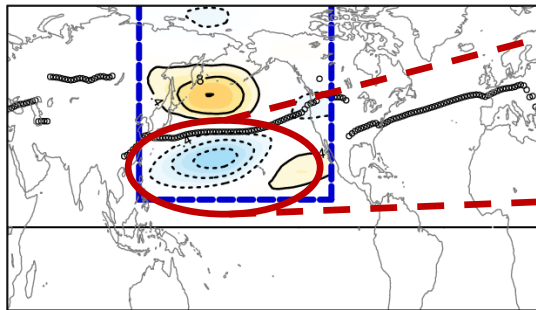


Not Poleward

Poleward

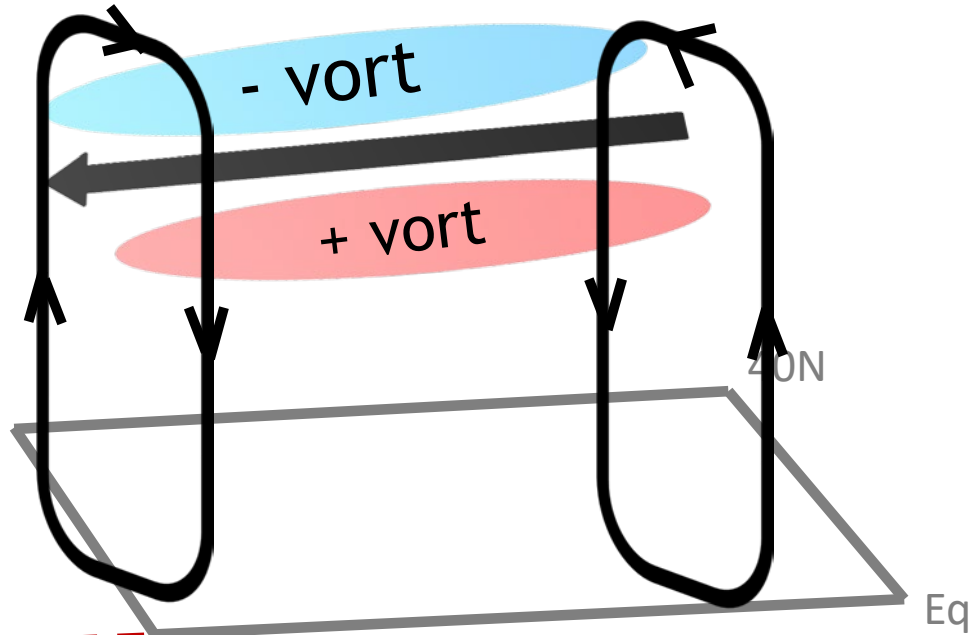
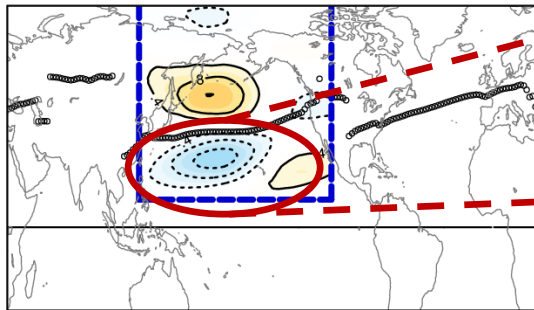
Is it surprising to have this connection between the divergent circulation in the tropics and the zonal wind anomalies in the extra-tropics?

Poleward - Not  
Poleward Difference



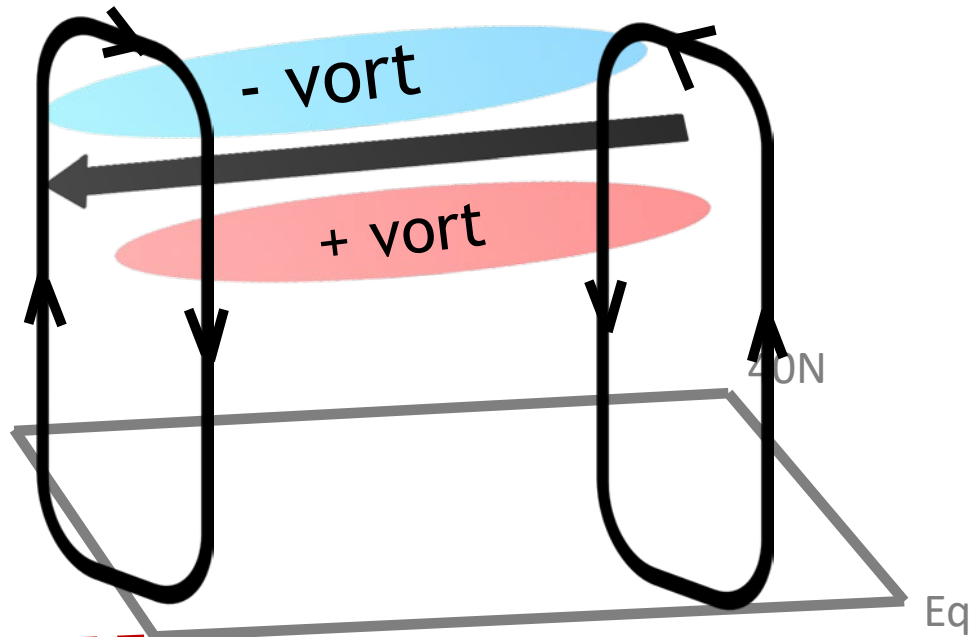
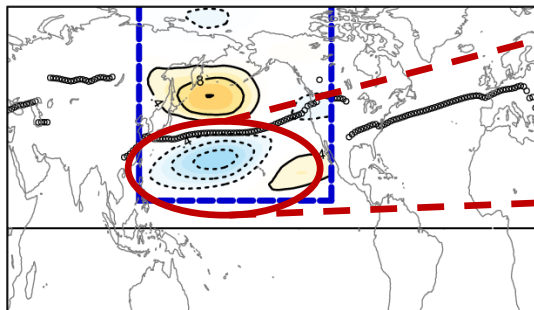
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Poleward - Not  
Poleward Difference

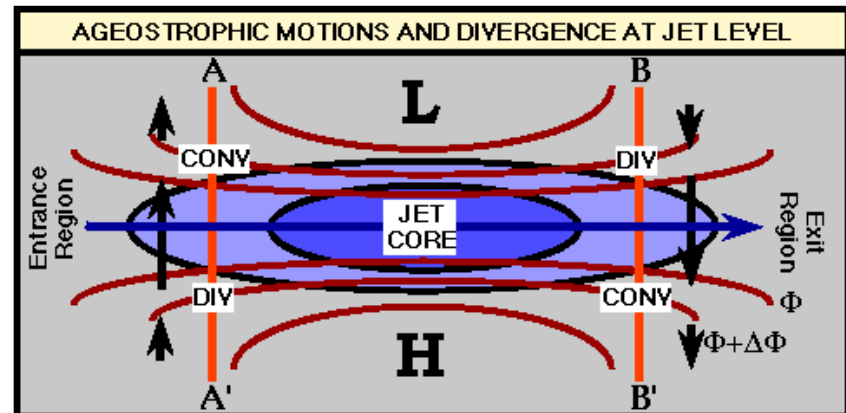


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Poleward - Not Poleward Difference

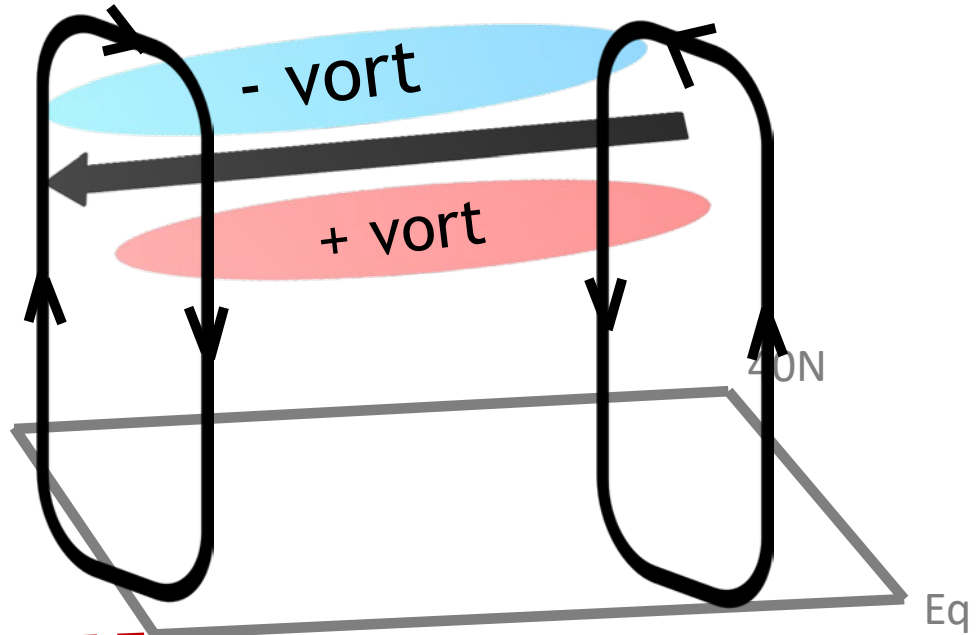
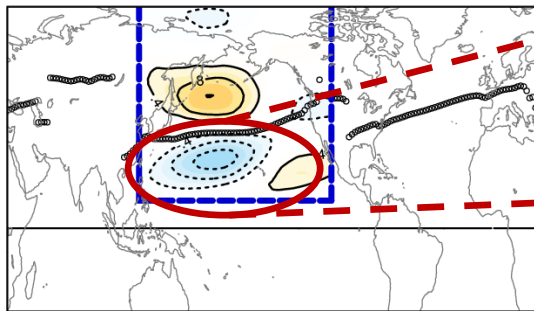


THE FOUR QUADRANT STRAIGHT JET MODEL



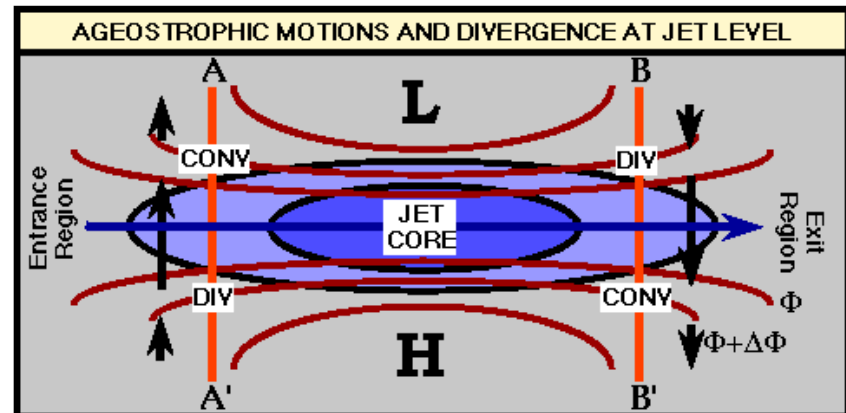
Is it surprising to have this connection between the divergent circulation in the tropics and the zonal wind anomalies in the extra-tropics?

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THE FOUR QUADRANT STRAIGHT JET MODEL

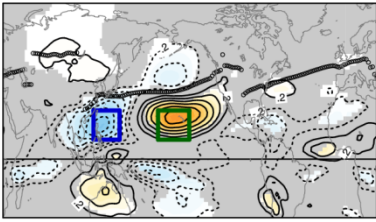
Divergent circulations at jet exit and entrance are predicted by quasi-geostrophic theory (omega equation) (Hoskins et al 1978)





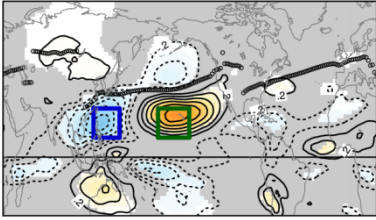
## Relationship between Future-Past difference and Past Climatologies

Poleward - Not Poleward



□ - □

Poleward - Not Poleward

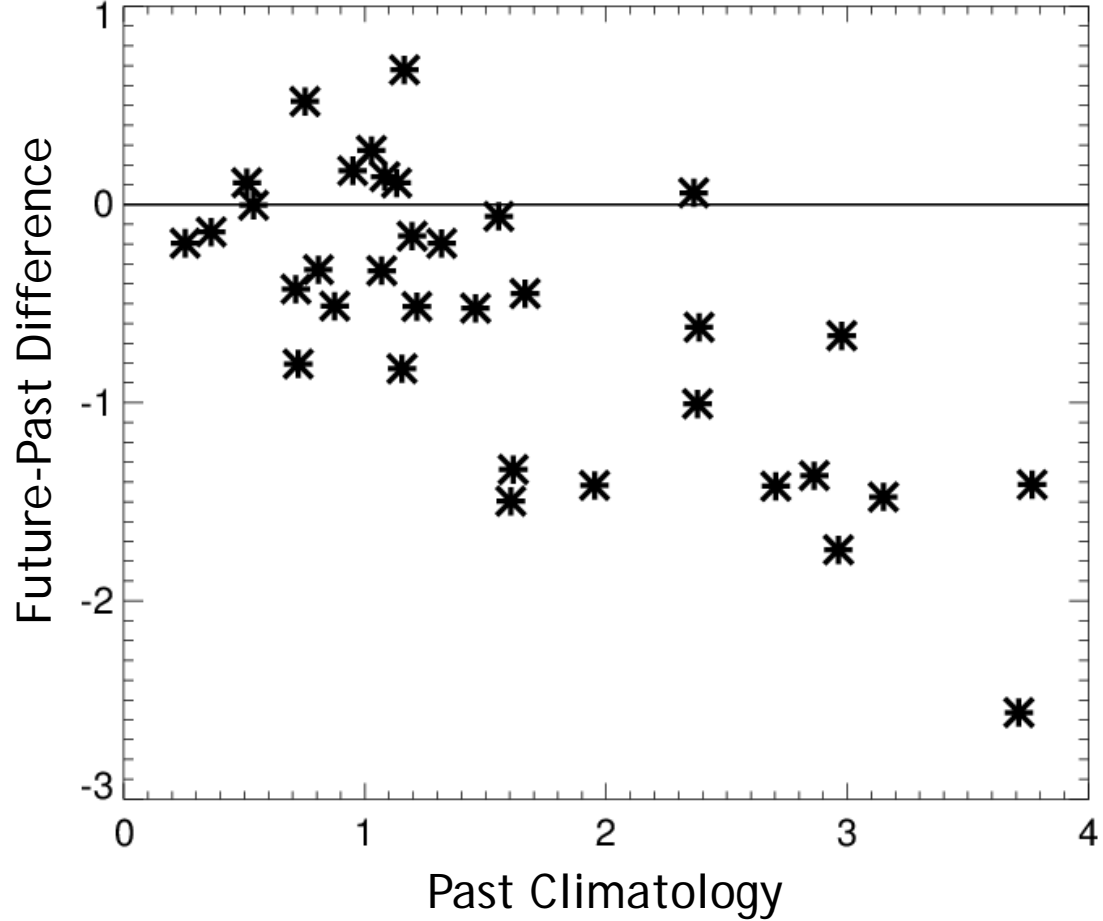


□ - □

Greater Walker Circulation Weakenings

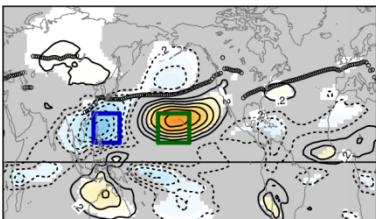


Vd (future-past) vs (past), correlation= -0.73



Stronger Climatological Walker Circulation

Poleward - Not Poleward

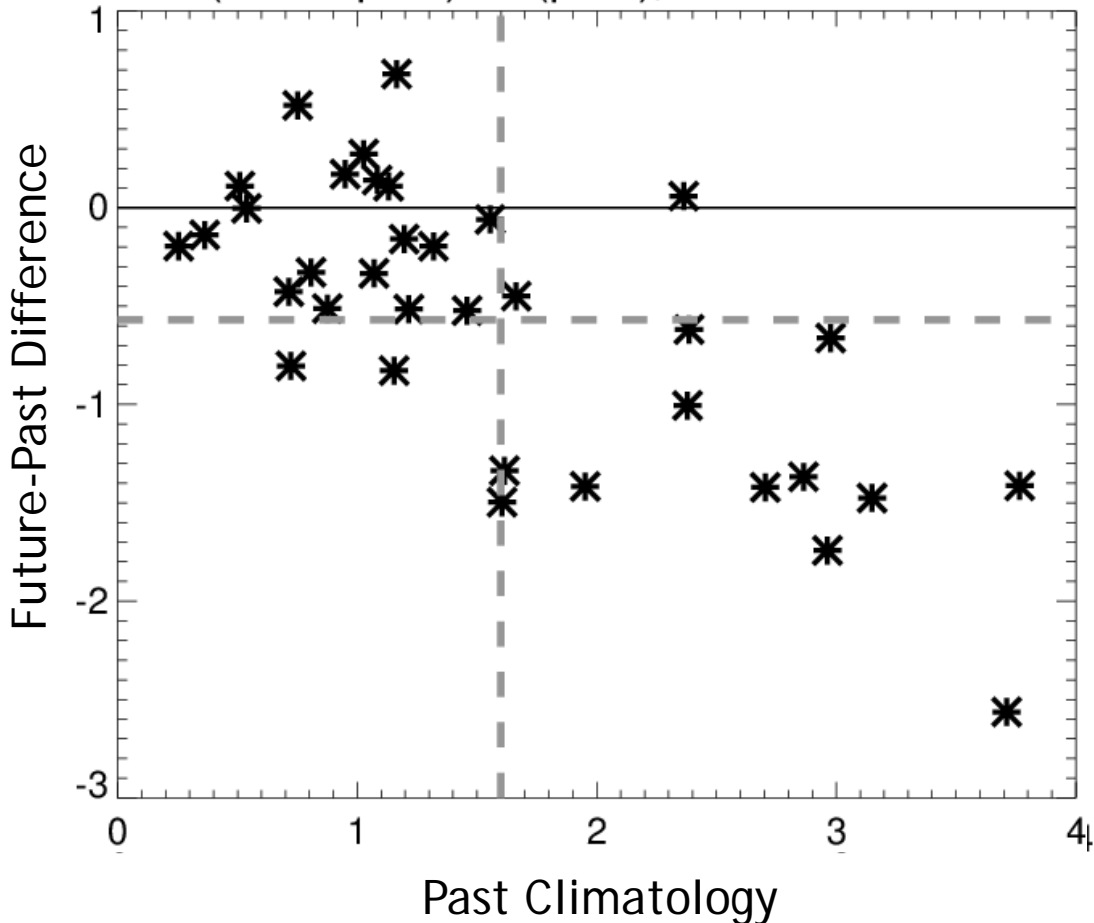


□ - □

Greater Walker Circulation Weakenings



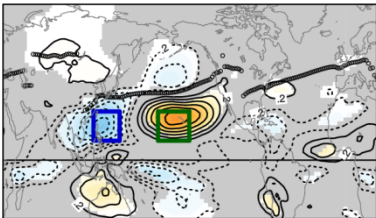
Vd (future-past) vs (past), correlation= -0.73



Stronger Climatological Walker Circulation



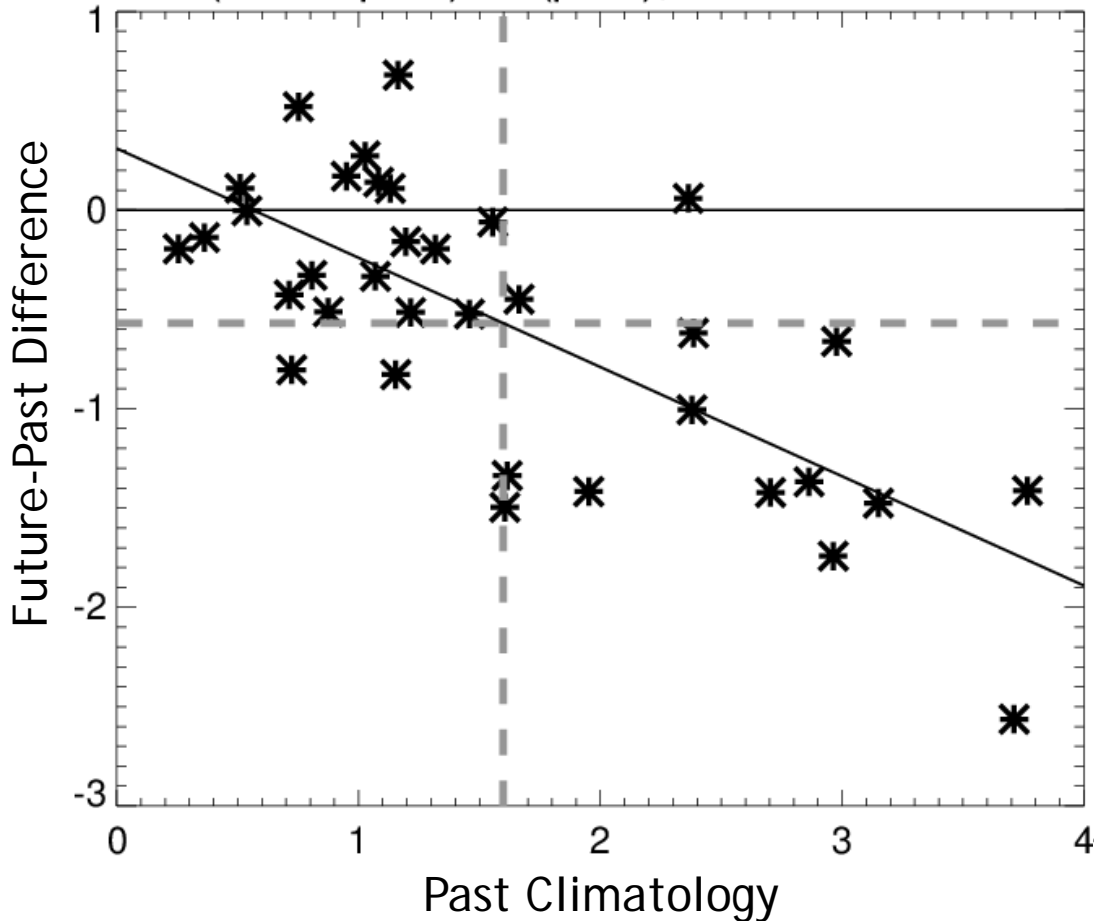
Poleward - Not Poleward



□ - □

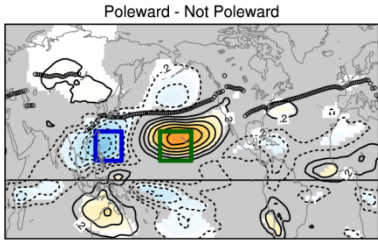
Greater Walker Circulation Weakenings

Vd (future-past) vs (past), correlation= -0.73



Stronger Climatological Walker Circulation



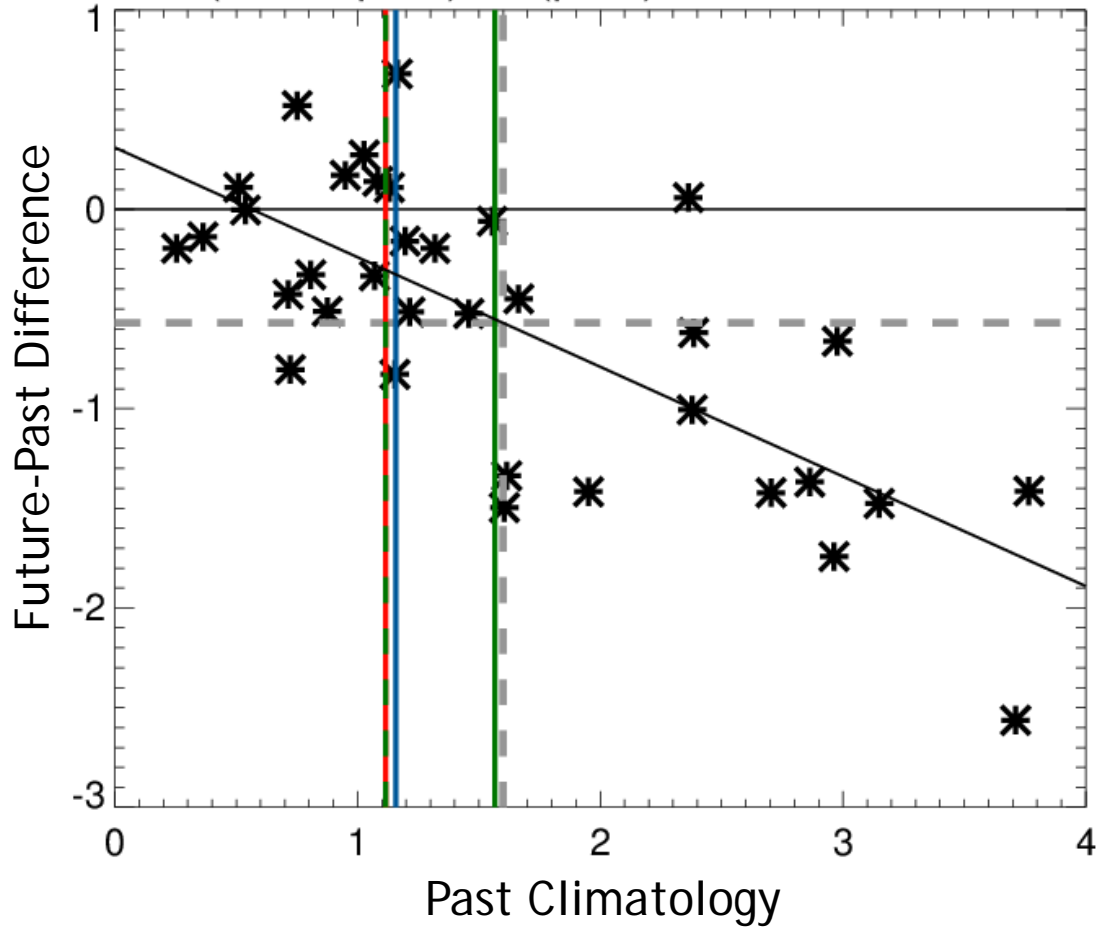


□ - □

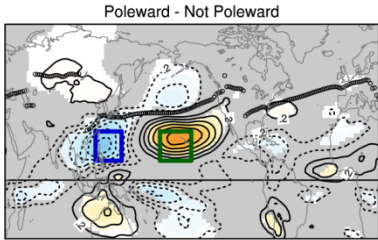
Greater Walker Circulation Weakenings

ERA-Interim MERRA MERRA-2 JRA-55

Vd (future-past) vs (past), correlation= -0.73



Stronger Climatological Walker Circulation

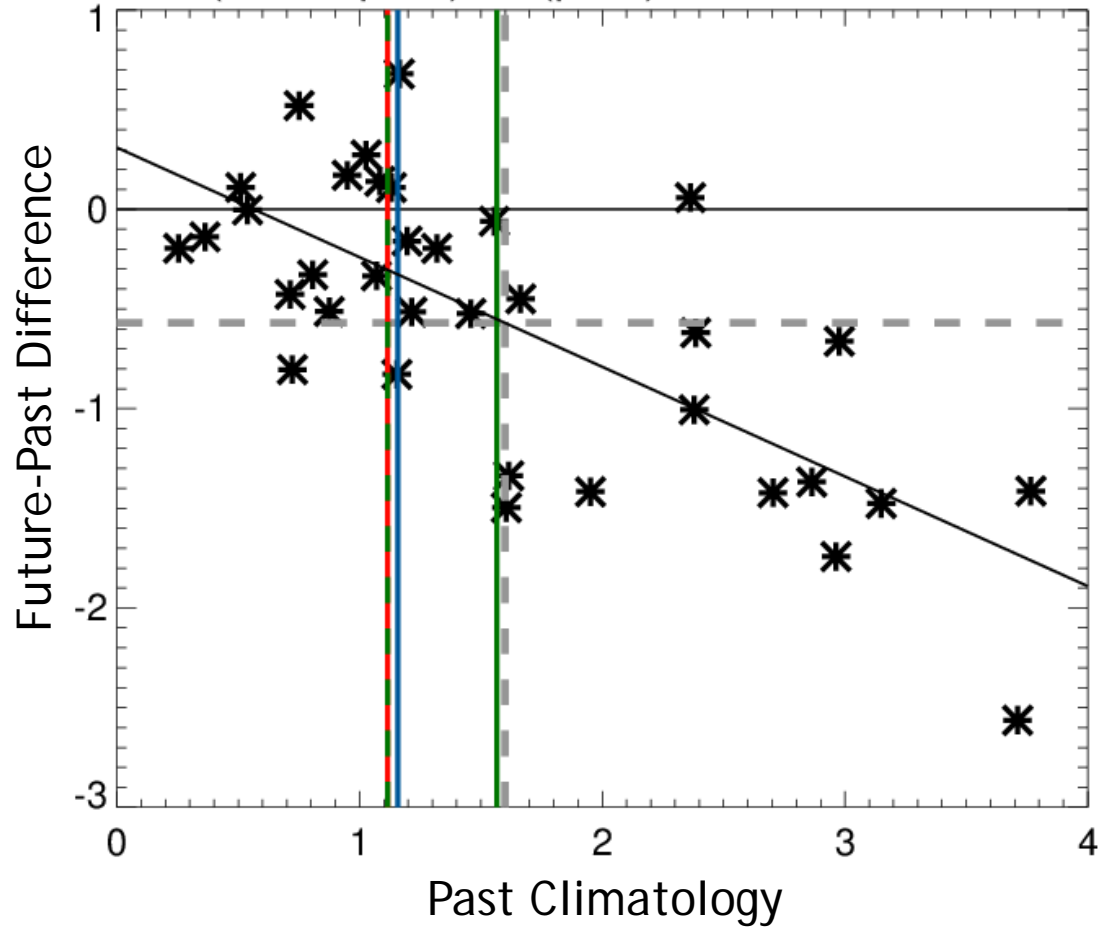


0 - 0

Greater Walker Circulation Weakenings

ERA-Interim MERRA MERRA-2 JRA-55

Vd (future-past) vs (past), correlation= -0.73



Stronger Climatological Walker Circulation

But Why?



Where should we start in trying to gain  
this understanding?

The tropics or the extra-tropics?

# A natural variability analogue in CESM

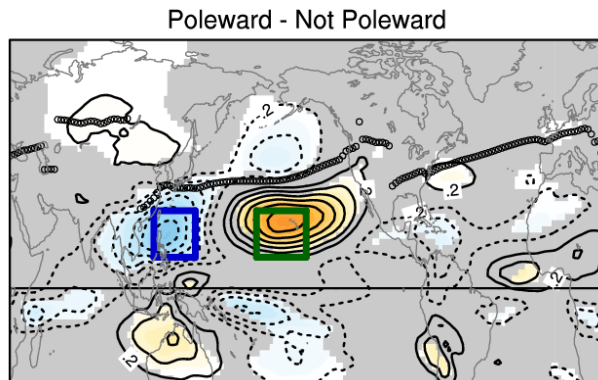
---

- 2600y long pre-industrial control simulation (CAM5, 1deg)
- Prescribed Climatological SSTs from coupled piControl run
- Inter-annual variability (DJF averages)



# A natural variability analogue in CESM

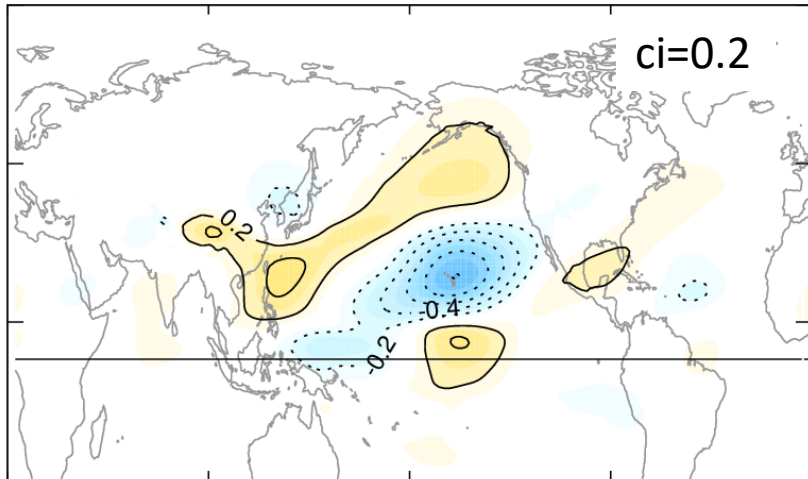
- 2600y long pre-industrial control simulation (CAM5, 1deg)
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- Inter-annual variability (DJF averages)



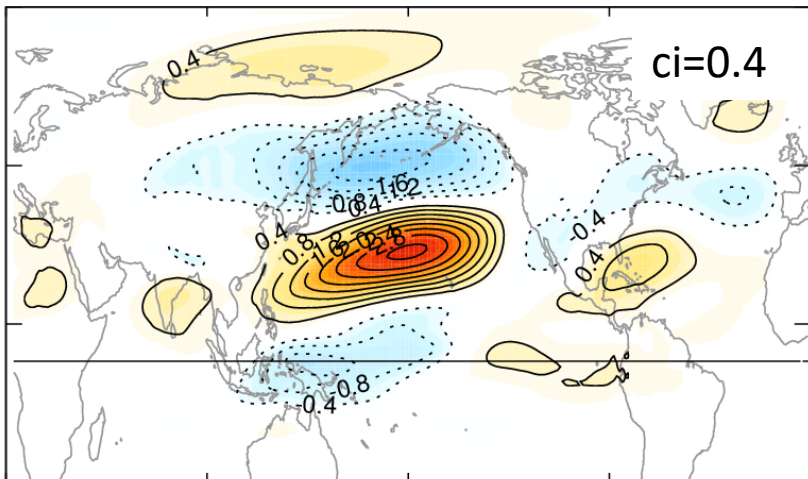
 —  Asymmetry in divergent tropical Pacific circulation

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

## 250hPa divergent v

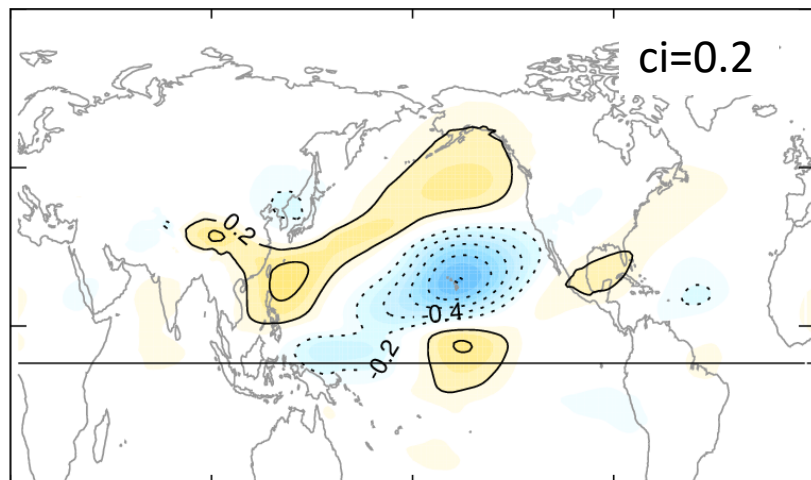


## 700hPa u

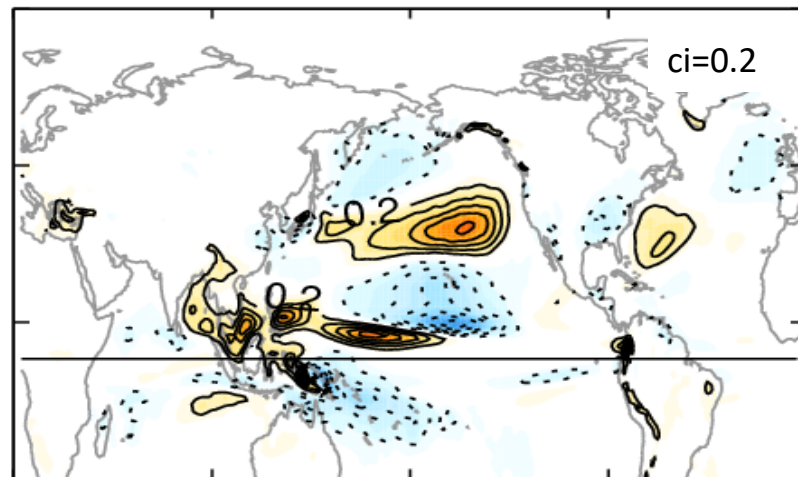


Regression onto interannual variability in divergent v index in the natural variability of CESM

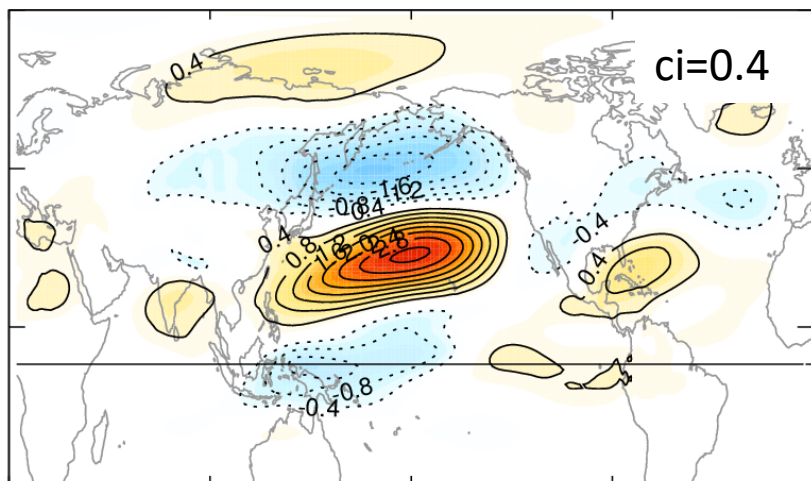
### 250hPa divergent v



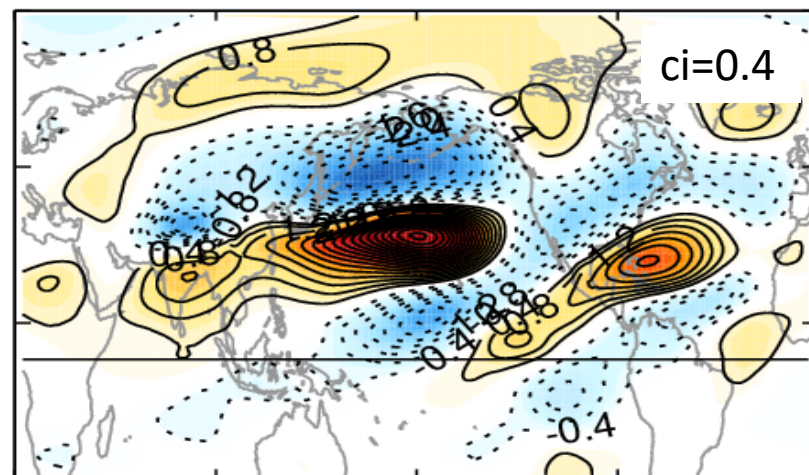
### Precipitation (mm/day)



### 700hPa u



### 250hPa u



Idealized experiments within CESM to identify the leader in these tropical/mid-latitude connections

Hypothesis 1: The tropics are the leader.



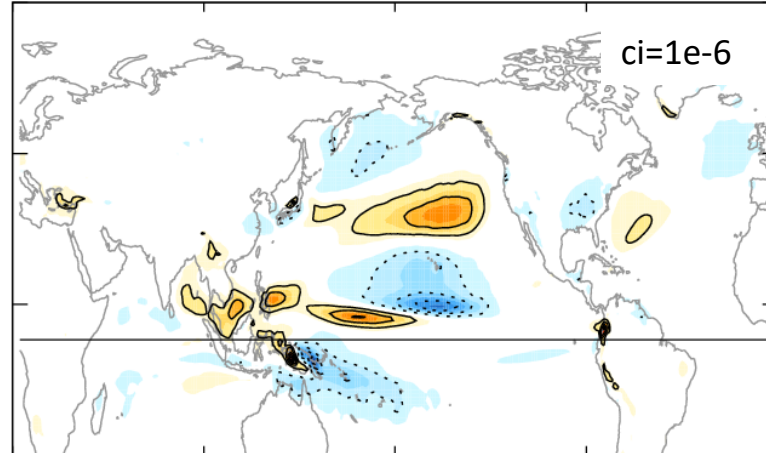
Hypothesis 1: The tropics are the leader.

e.g., some organization of tropical precipitation and diabatic heating, forcing extra-tropical circulation anomalies

# Diabatic Heating Anomalies

Heating anomalies (from moist processes) associated with interannual variability

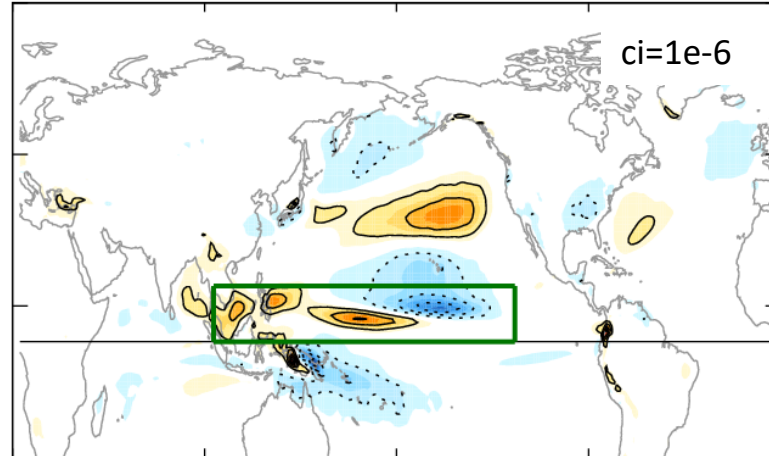
Vertically Integrated  
Condensational Heating  
( $\text{Ks}^{-1}$ ) from regression



# Diabatic Heating Anomalies

Heating anomalies (from moist processes) associated with interannual variability

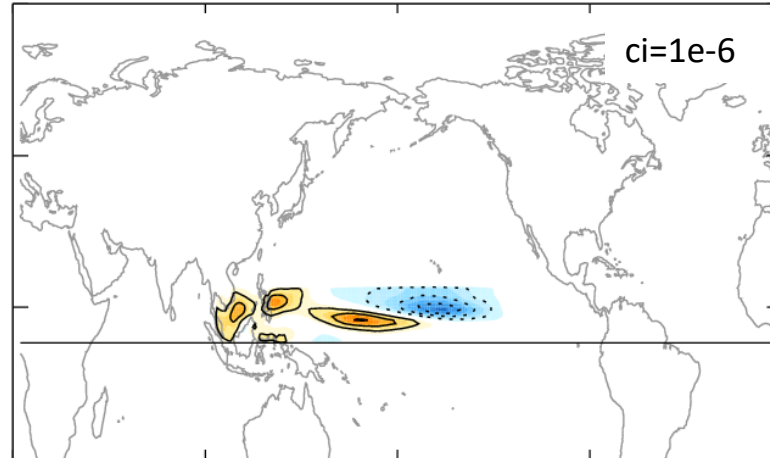
Vertically Integrated  
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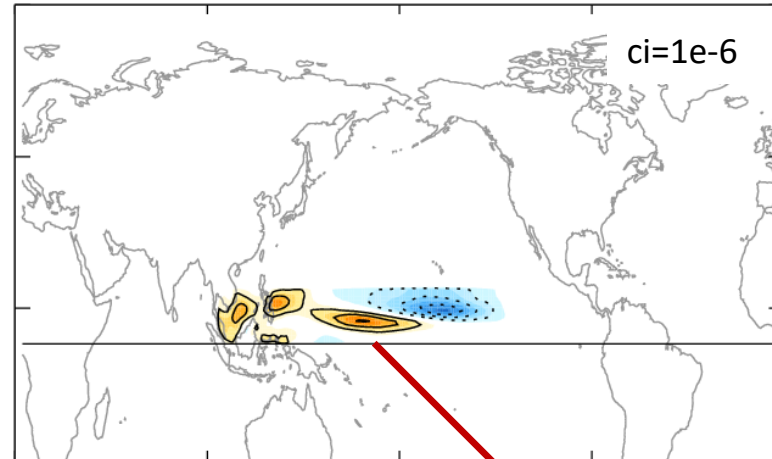
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# Diabatic Heating Anomalies

Heating anomalies (from moist processes) associated with interannual variability

Vertically Integrated  
Condensational Heating  
(Ks<sup>-1</sup>) from regression



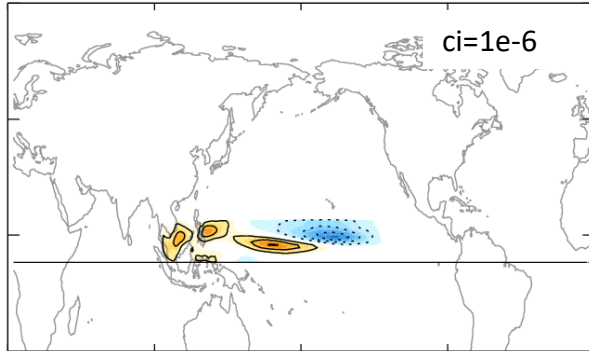
Impose a temperature tendency  
within the model (CAM4, 2deg)

$$\frac{\partial T}{\partial t} = \dots + T_{tend}$$

Thanks to Patrick Callaghan

# Heating Perturbation Experiment Results

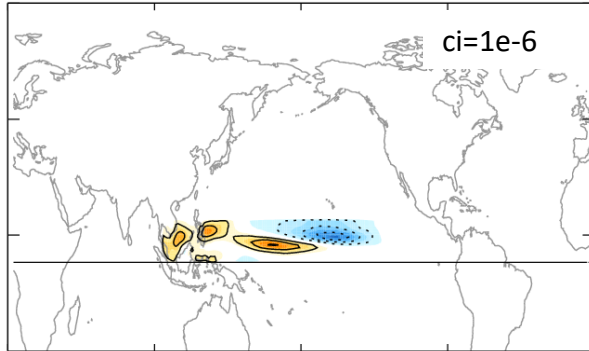
(a) Imposed T tendency ( $\text{Ks}^{-1}$ )



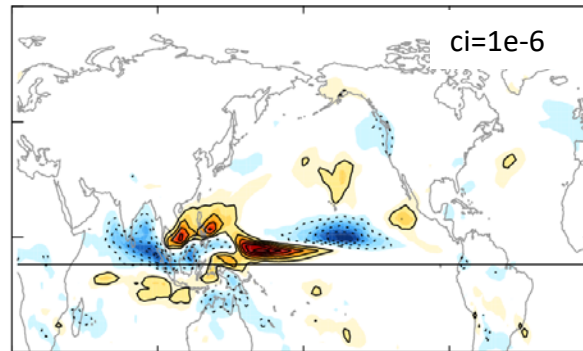


# Heating Perturbation Experiment Results

(a) Imposed T tendency ( $\text{Ks}^{-1}$ )

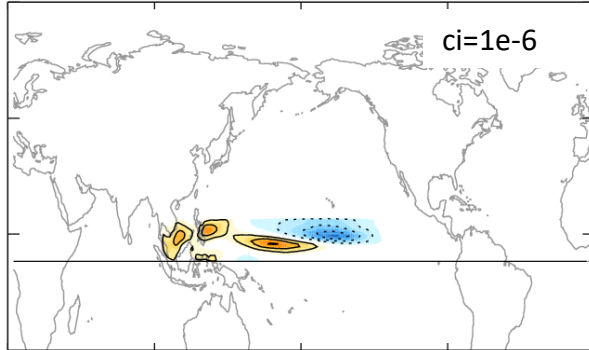


(b) T tendency response ( $\text{Ks}^{-1}$ )

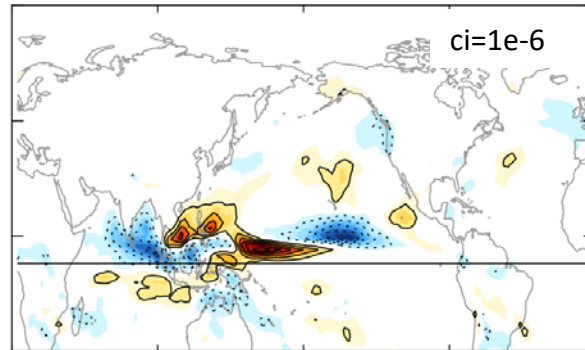


# Heating Perturbation Experiment Results

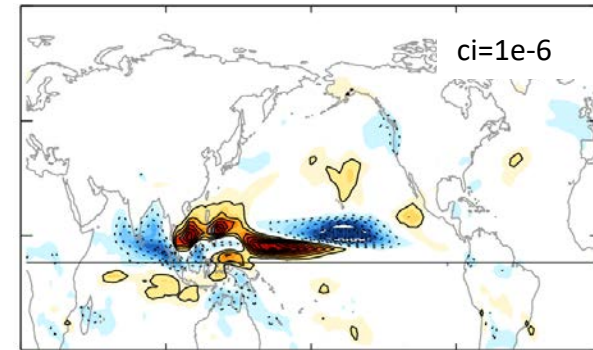
(a) Imposed T tendency ( $\text{Ks}^{-1}$ )



(b) T tendency response ( $\text{Ks}^{-1}$ )

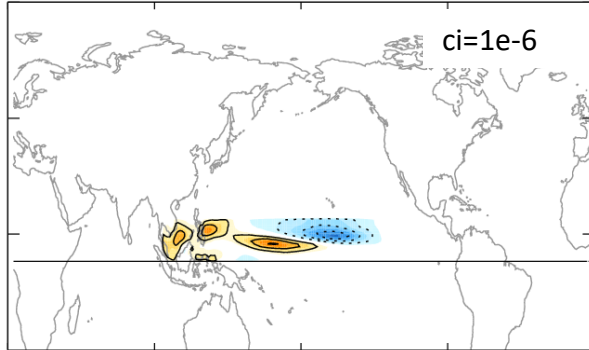


(a) + (b)

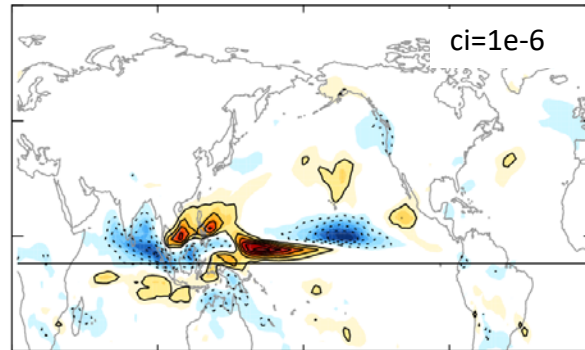


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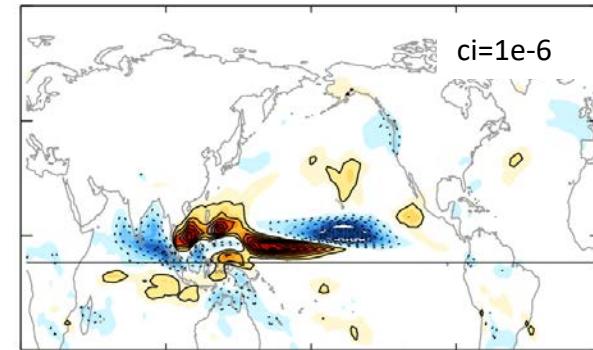
(a) Imposed T tendency ( $\text{Ks}^{-1}$ )



(b) T tendency response ( $\text{Ks}^{-1}$ )

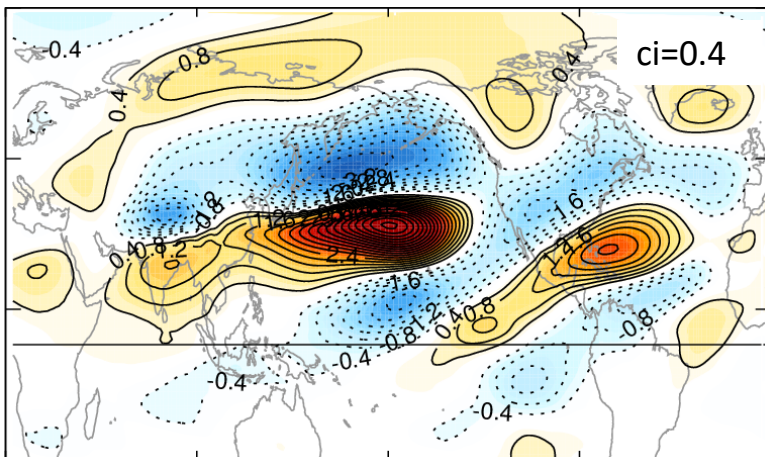


(a) + (b)



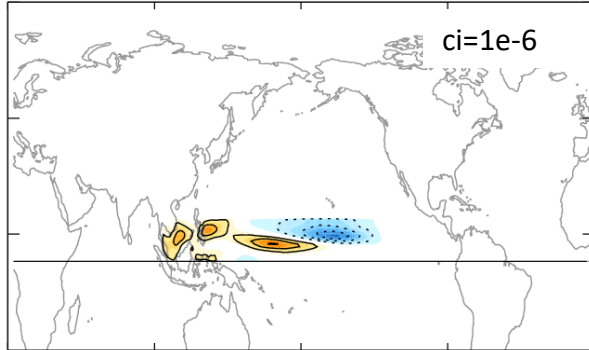
Can we reproduce this?

250hPa u (interannual variability regression)

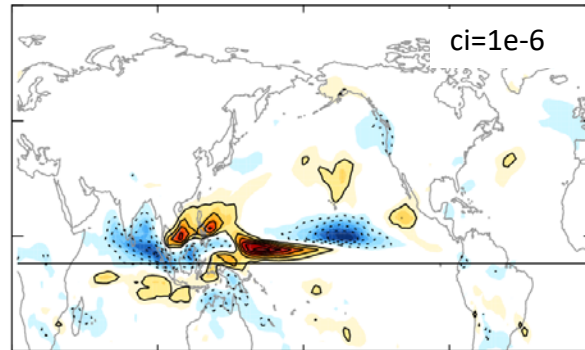


# Heating Perturbation Experiment Results

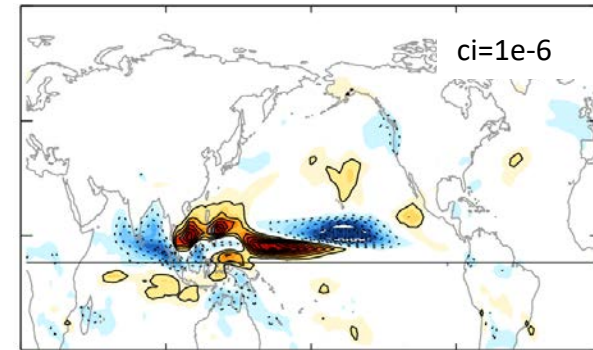
(a) Imposed T tendency ( $Ks^{-1}$ )



(b) T tendency response ( $Ks^{-1}$ )

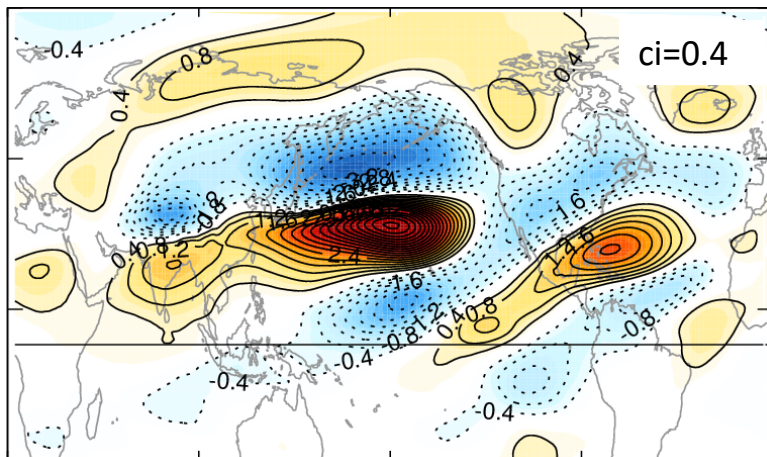


(a) + (b)

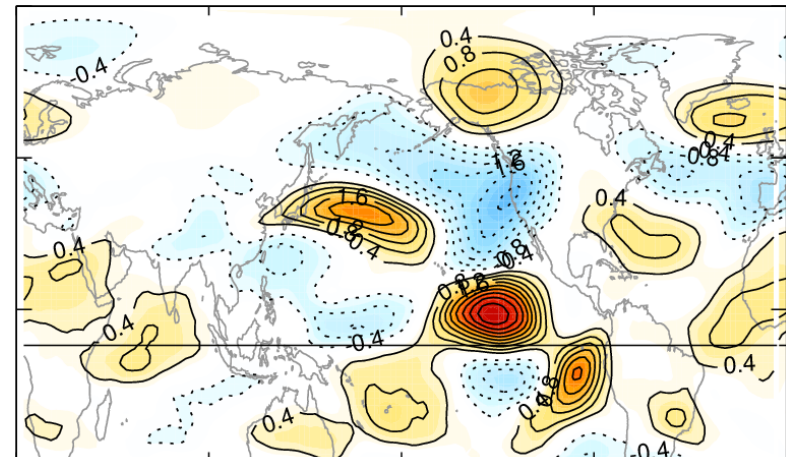


Can we reproduce this?

250hPa u (interannual variability regression)



250hPa u (response to heating perturbation)



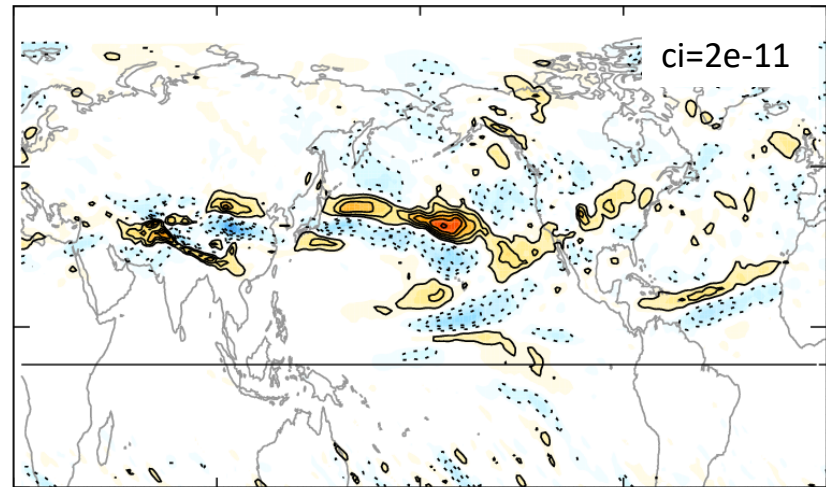
Hypothesis 2: The mid-latitudes are the leader.

Hypothesis 2: The mid-latitudes are the leader.

e.g., a transient eddy driven shift in the westerlies with impacts on the tropical circulation

# Transient Eddy Vorticity Flux Convergence

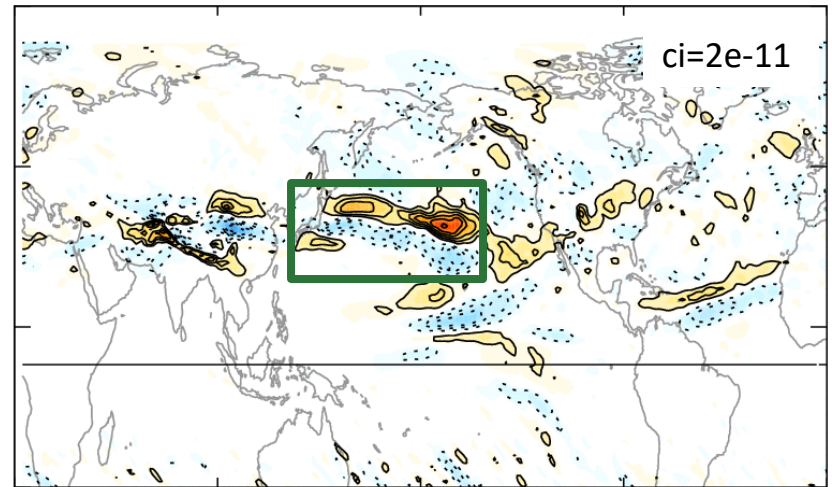
250hPa transient vorticity  
flux convergence regression  
onto divergent v index ( $s^{-1}$ )





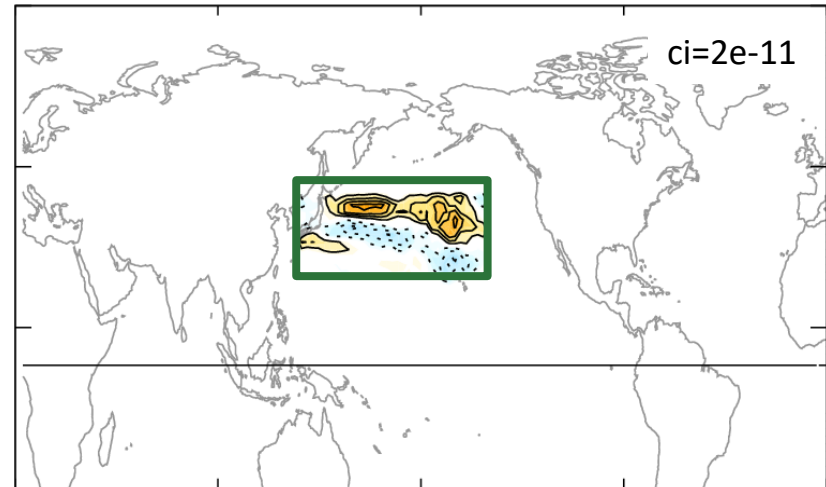
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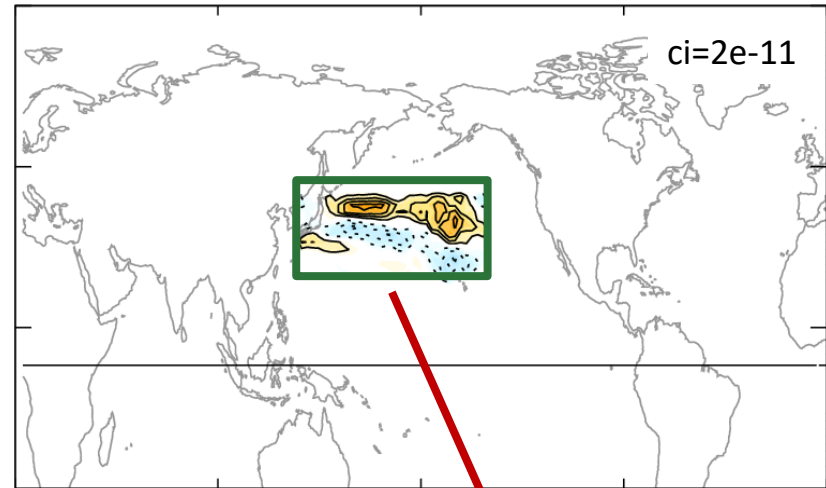
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250hPa transient vorticity  
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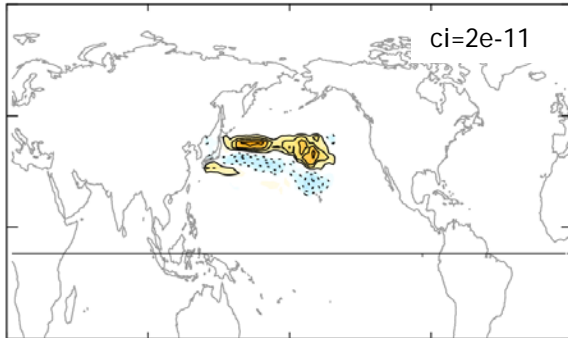


Impose a vorticity tendency within  
the model (CAM4, 2deg)

$$\frac{\partial \zeta}{\partial t} = \dots + \zeta_{tend}$$

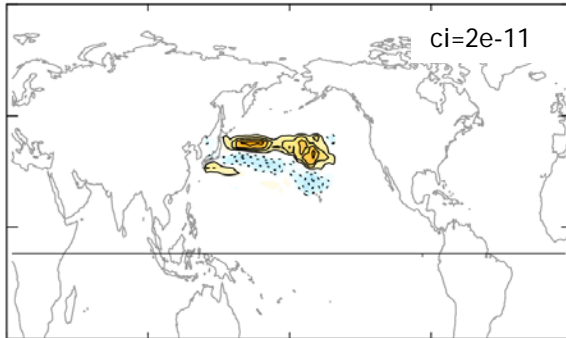
# Vorticity perturbation experiment results

(a) Imposed vorticity tendency

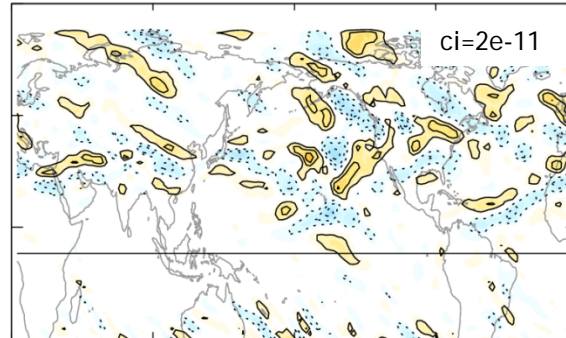


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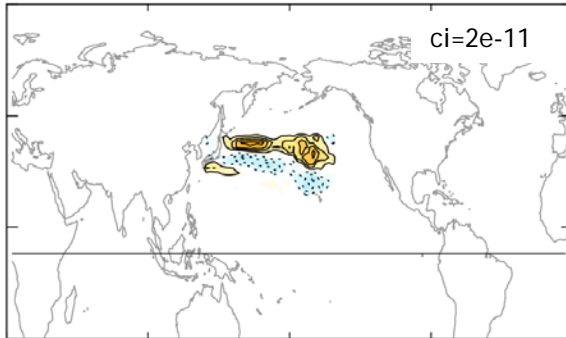


(b)  $-\nabla \cdot (\overline{v' \zeta'})$  response

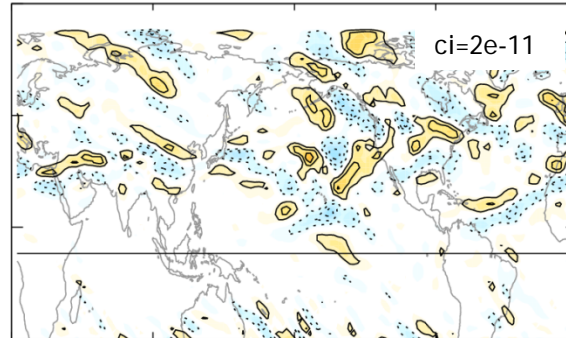


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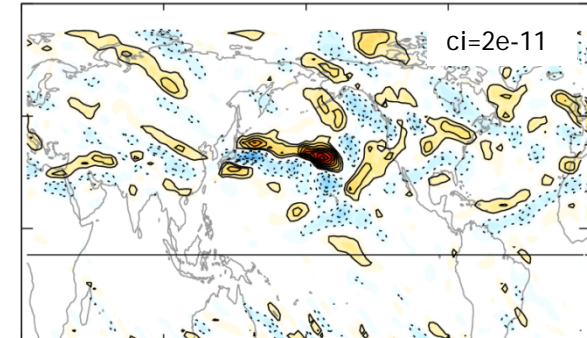
(a) Imposed vorticity tendency



(b)  $-\nabla \cdot (\overline{v' \zeta'})$  response

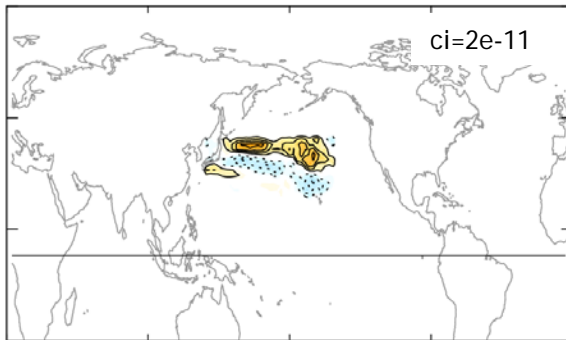


(c) (a) + (b)

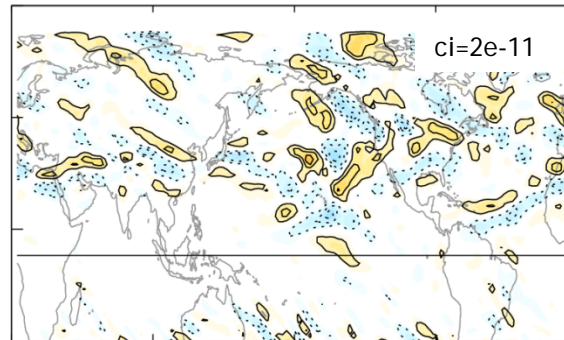


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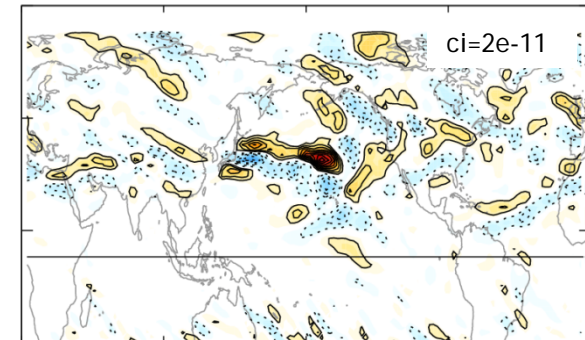
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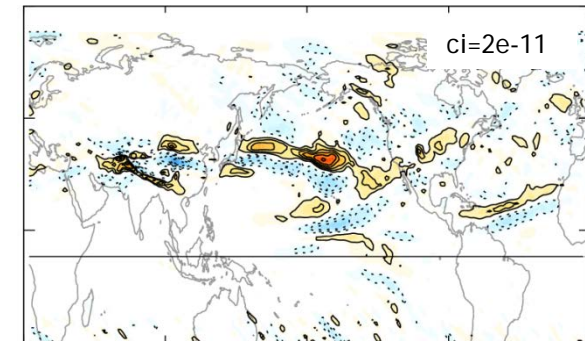
(b)  $-\nabla \cdot (\overline{v' \zeta'})$  response



(c) (a) + (b)



Transient vorticity flux convergence  
regression onto divergent v index

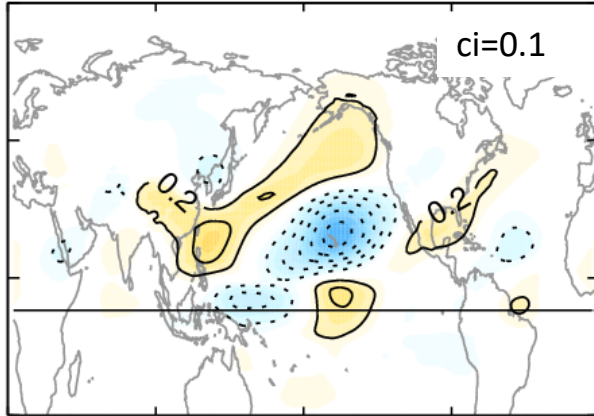




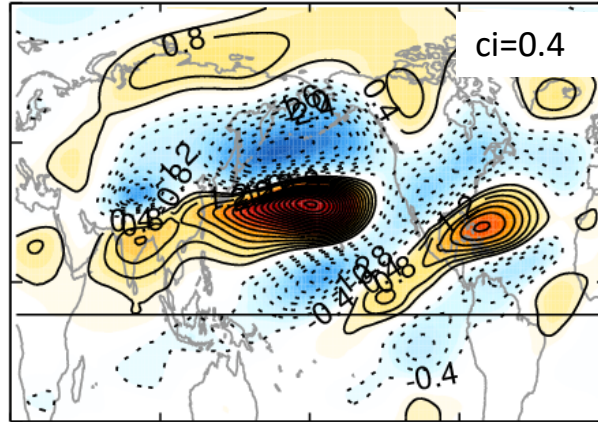
# Can we reproduce this?

(regressions onto divergent v index)

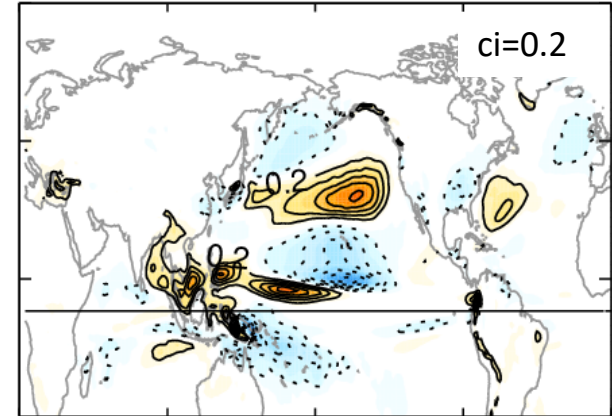
250hPa divergent v



250hPa u



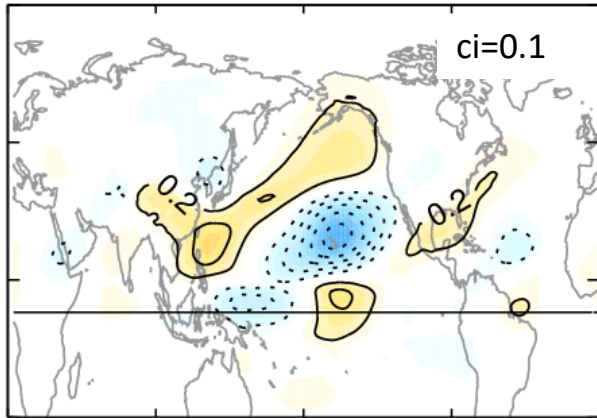
Precipitation (mm/day)



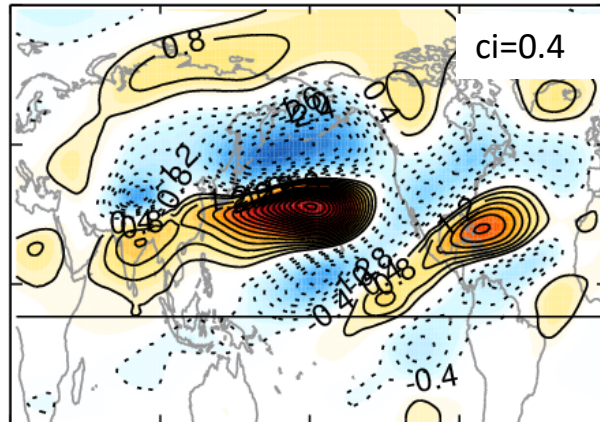
# Can we reproduce this?

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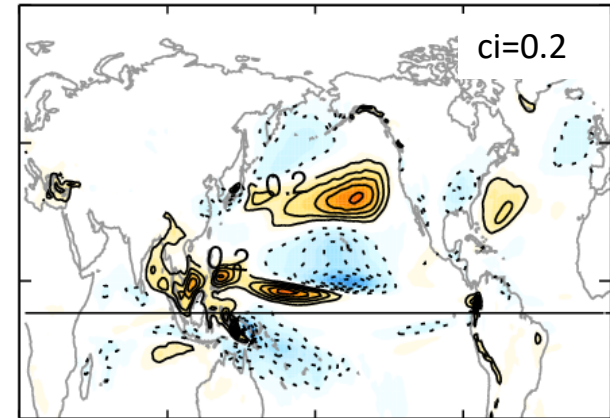
250hPa divergent v



250hPa u

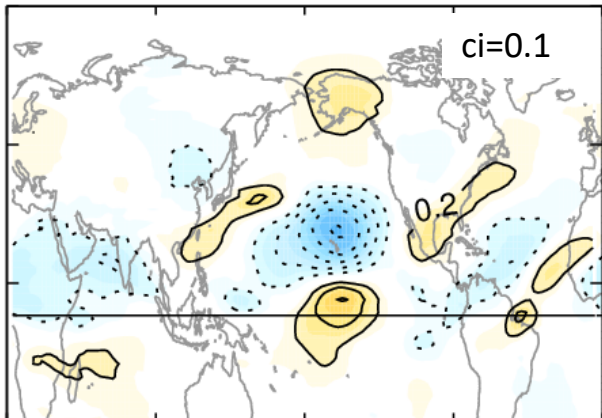


Precipitation (mm/day)

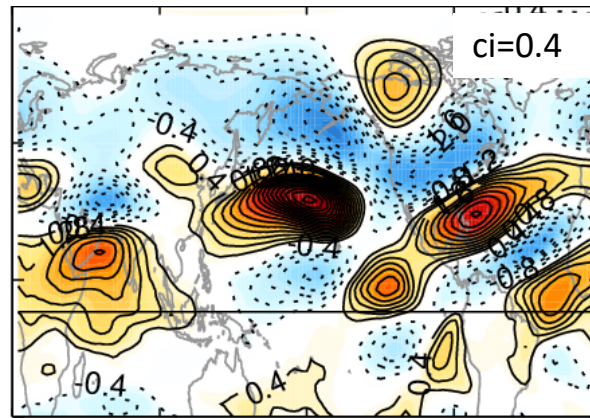


# Response to vorticity tendency

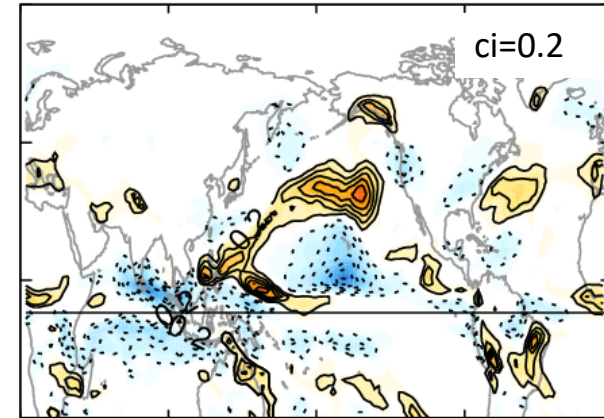
250hPa divergent v



250hPa u



Precipitation (mm/day)



The origin of the different behavior among the models likely lies in the extra-tropics.

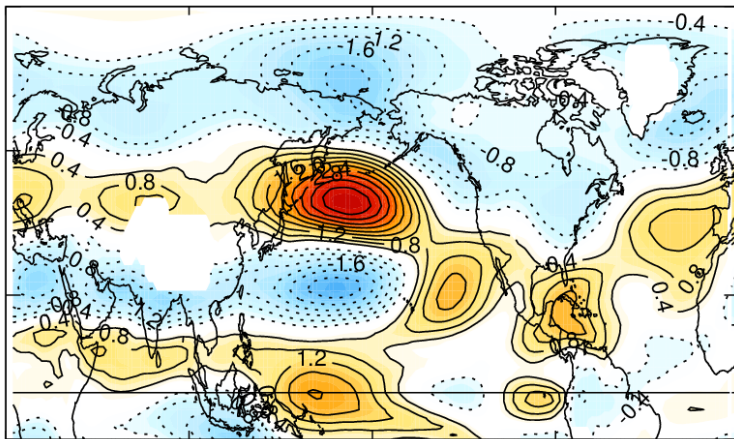
Why?



# What I'm trying to do now...

- CCSM4 is a “not poleward” model

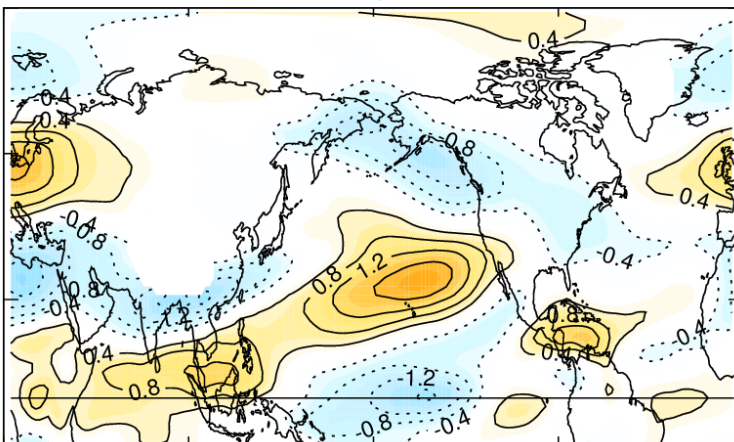
Poleward, Future-Past



← Poleward

700hPa zonal wind  
Future-Past

Not Poleward, Future-Past



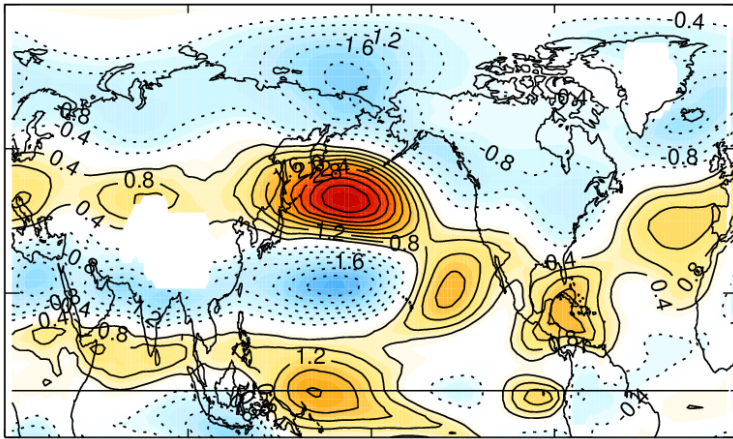
← Not Poleward



# What I'm trying to do now...

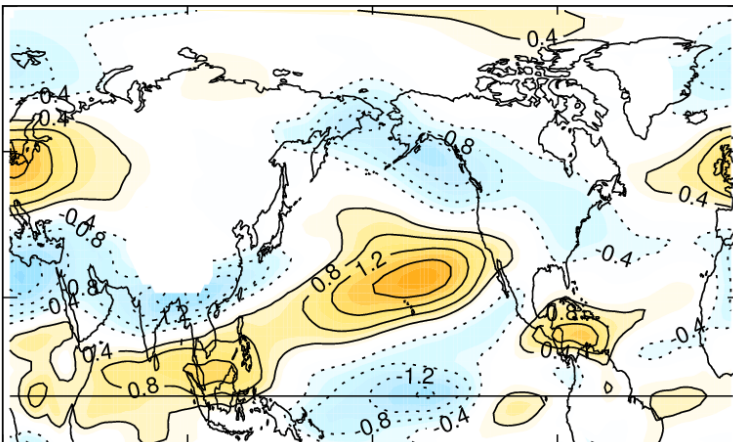
- CCSM4 is a “not poleward” model

Poleward, Future-Past

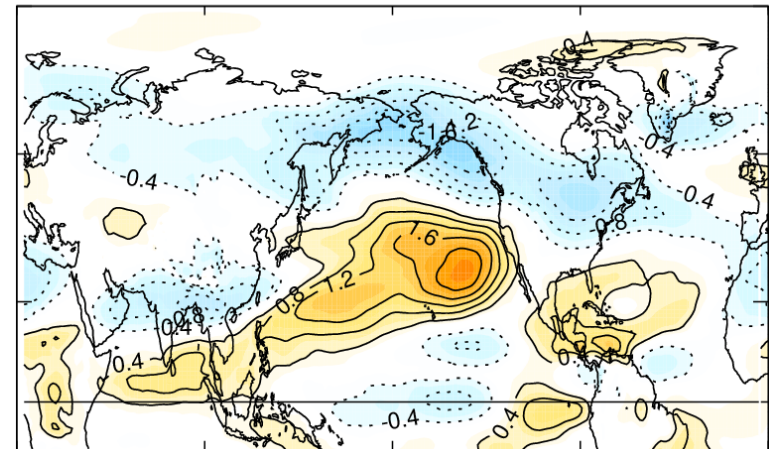


CCSM4

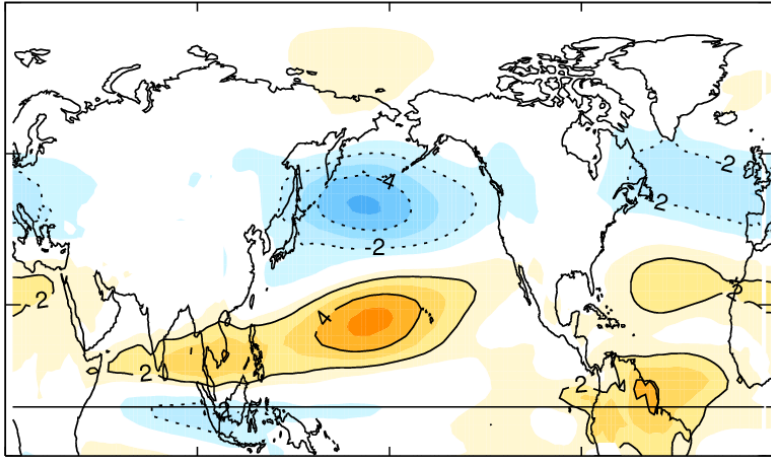
Not Poleward, Future-Past



CCSM4, Future-Past



Poleward - Not Poleward, Past



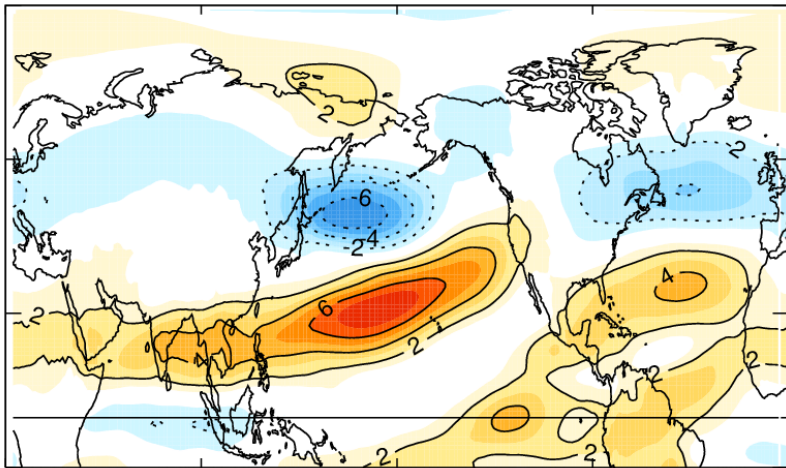
Past Climatology  
Poleward - Not Poleward



Force CCSM4 to have more  
equatorward westerlies via an  
imposed vorticity tendency

(CCSM4\_EQ)

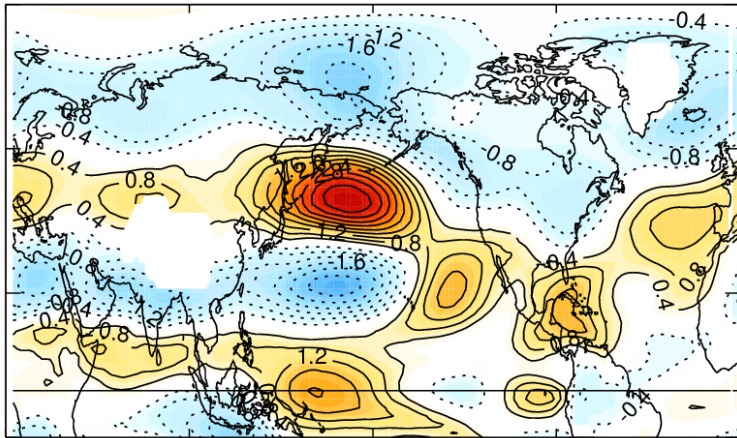
CCSM4 - CCSM4\_EQ





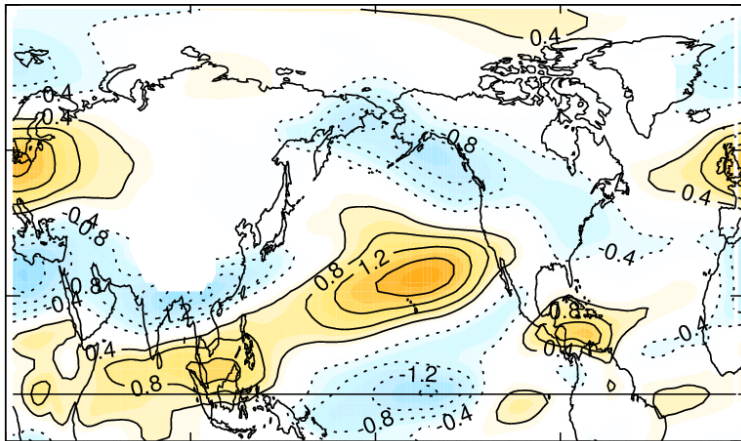
# Future - Past Differences

Poleward, Future-Past



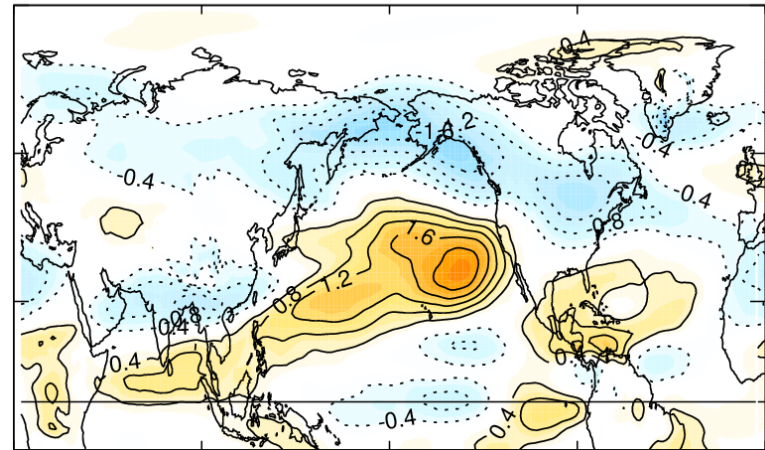
Poleward

Not Poleward, Future-Past



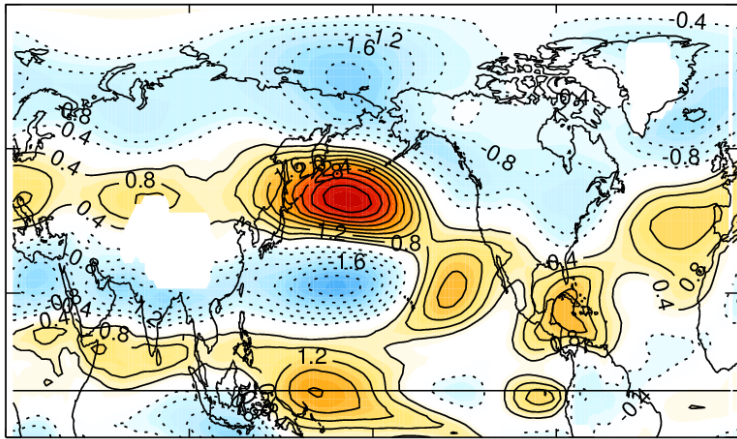
Not Poleward

CCSM4, Future-Past



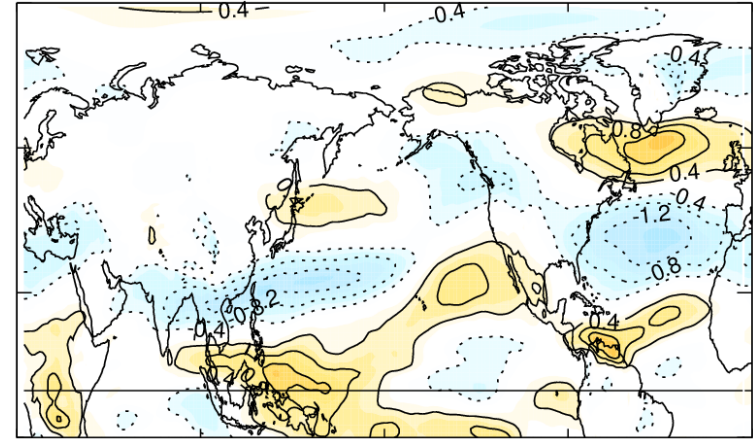
# Future - Past Differences

Poleward, Future-Past

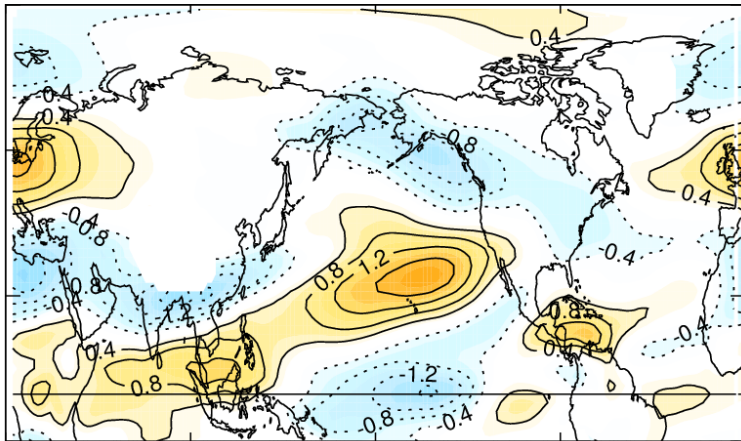


Poleward

CCSM4\_EQ, Future-Past

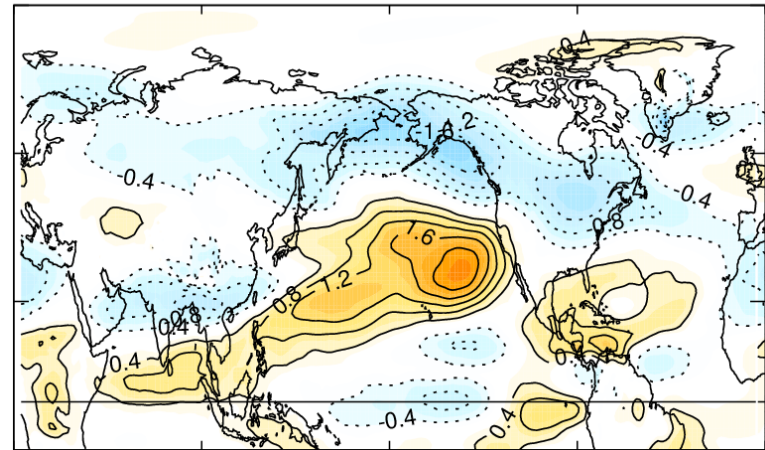


Not Poleward, Future-Past



Not Poleward

CCSM4, Future-Past



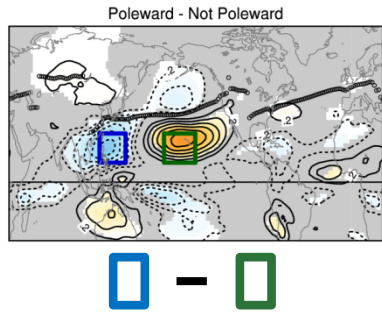
# Conclusions

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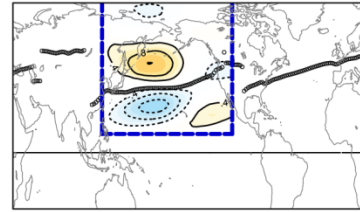
- Models exhibit diverse behavior in the tropical and extra-tropical Pacific circulation response to climate change in DJF.
- The tropical and the extra-tropical responses are highly correlated.
- A model's response is also strongly related to its climatological circulation.
- Models with a more equatorward westerly jet stream and stronger Walker circulation in their present day climatologies exhibit stronger poleward shifting of the westerlies and weakening of the Walker circulation.
- Hypothesis: The climatology of the westerly jets stream governs the models extra-tropical westerly jet stream response to climate change. How the extra-tropical westerlies change has an impact on the tropics.

We already have mechanisms proposed for why jet latitude affects the strength of eddy feedbacks/forced responses (Barnes et al 2010, Simpson et al 2012). Hopefully further analysis of CCSM4 runs will indicate whether these, or other mechanisms apply here.

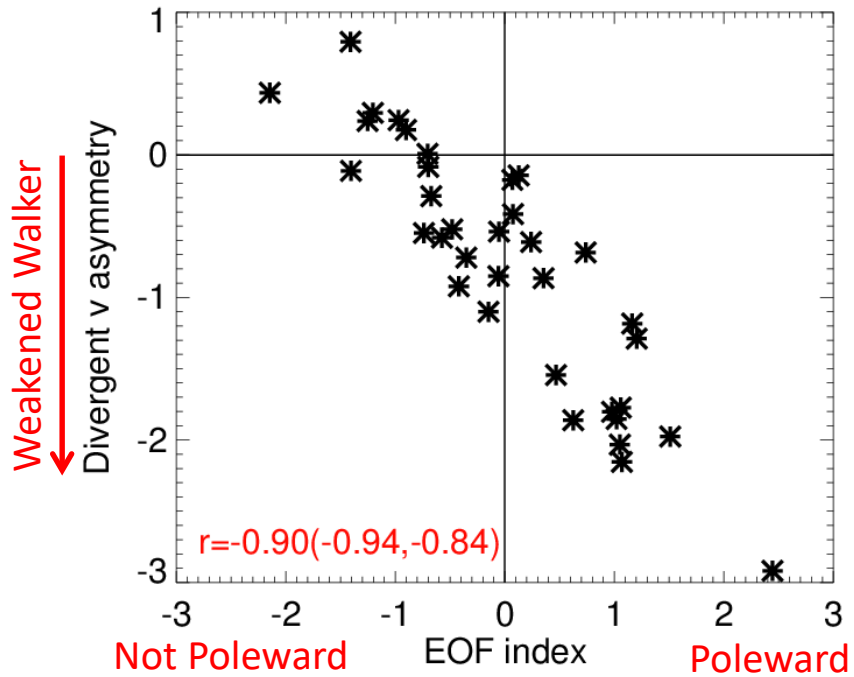


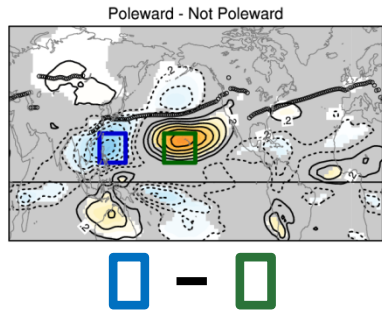


versus

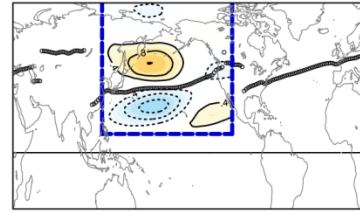


### Future - Past Differences

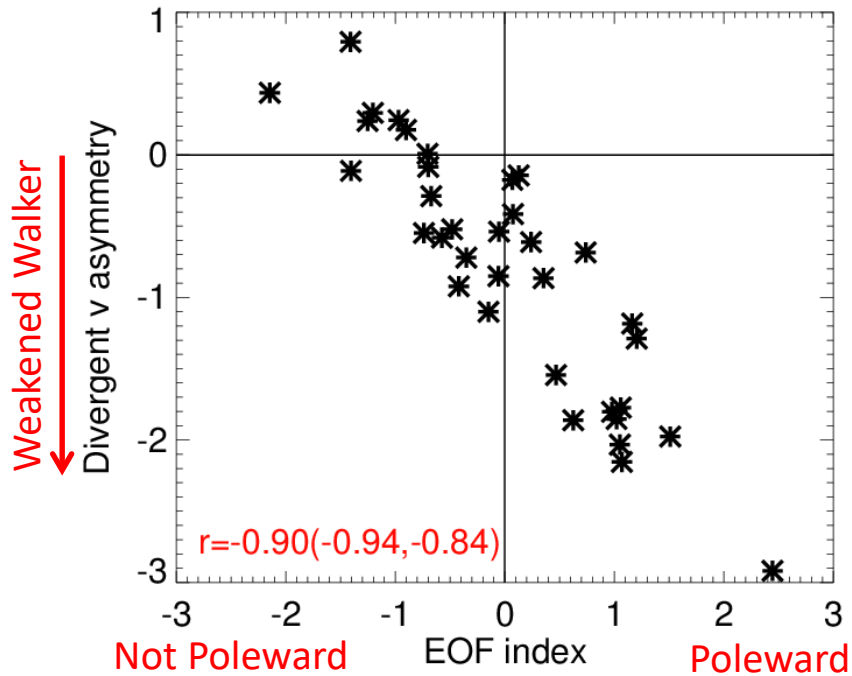




versus

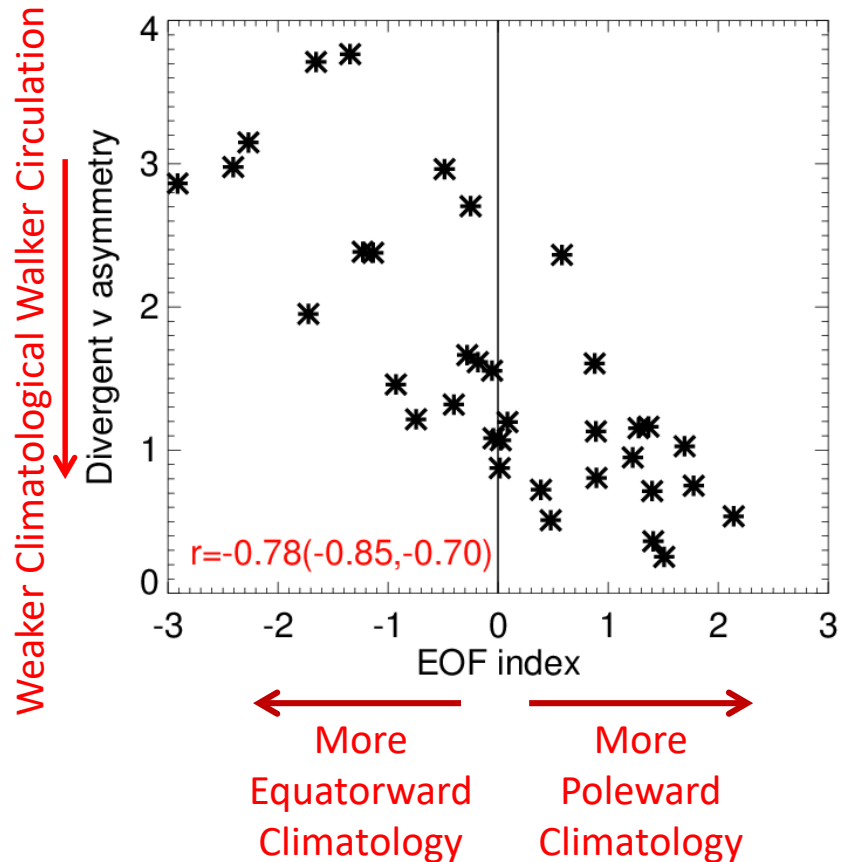


### Future - Past Differences



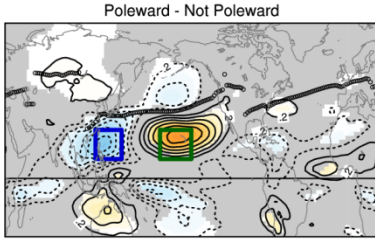
### Past Climatologies

(Anomalies from the multimodel mean)

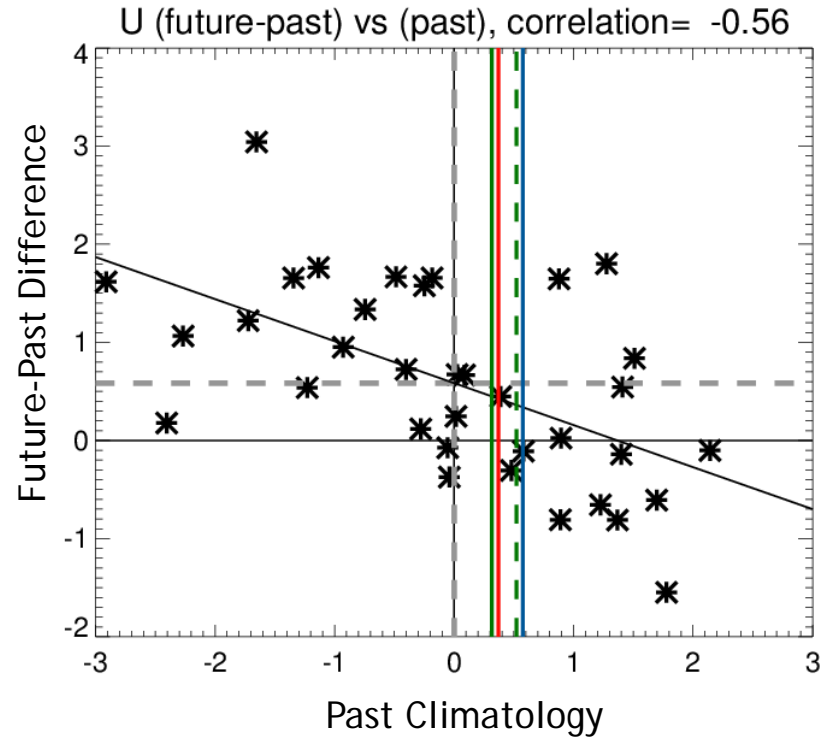
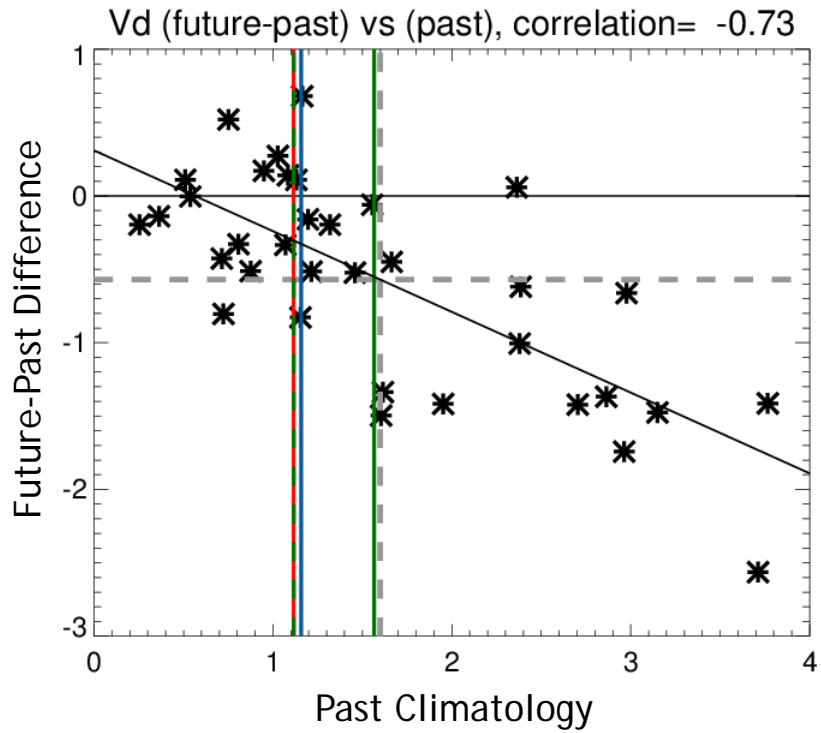
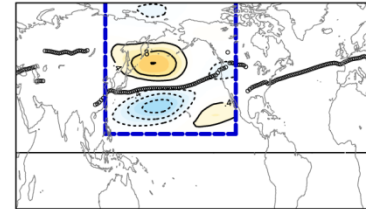




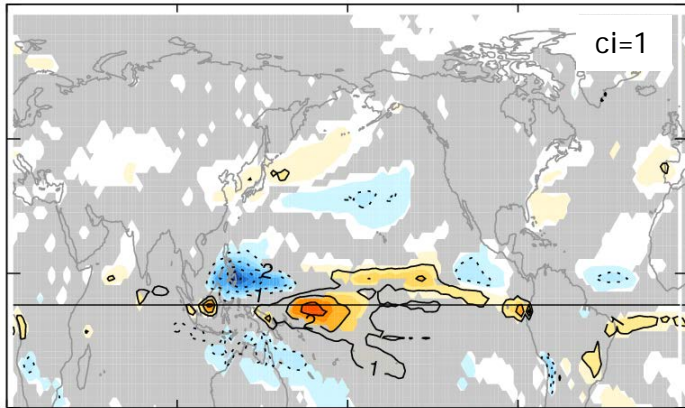
# Divergent V Index



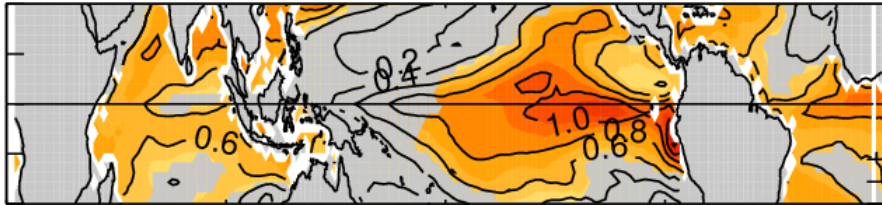
# U Index







Poleward – Not Poleward  
precipitation anomalies (mm/day)



Poleward – Not Poleward  
SST anomalies (K)

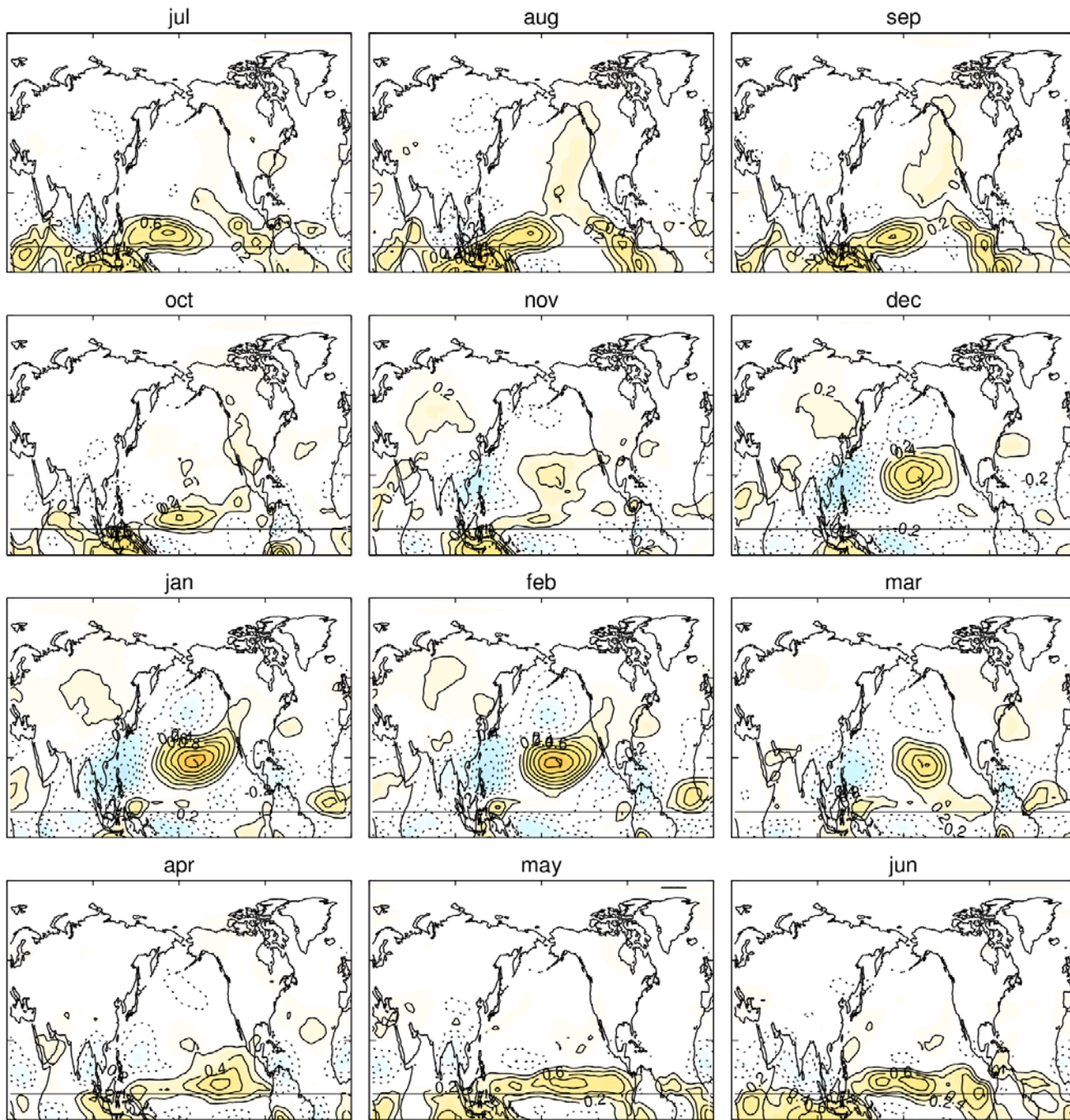
## Poleward Models

CMCC-CM  
CMCC-CMS  
CSIRO-Mk3-6-0  
GISS-E2-R  
IPSL-CM5A-MR  
MIROC5  
MPI-ESM-LR  
MPI-ESM-MR  
MRI-CGCM3

## Not Poleward Models

BNU-ESM  
CanESM2  
CCSM4  
CNRM-CM5  
FIO-ESM  
GFDL-ESM2G  
GFDL-ESM2M  
inmcm4  
NorESM1-ME

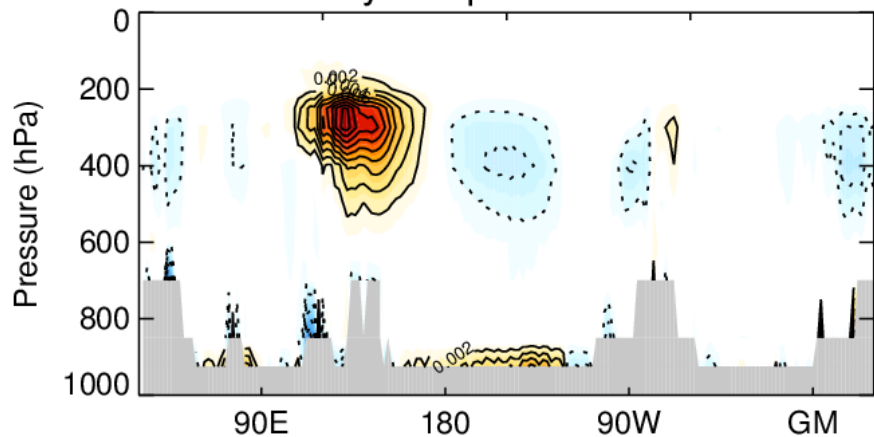




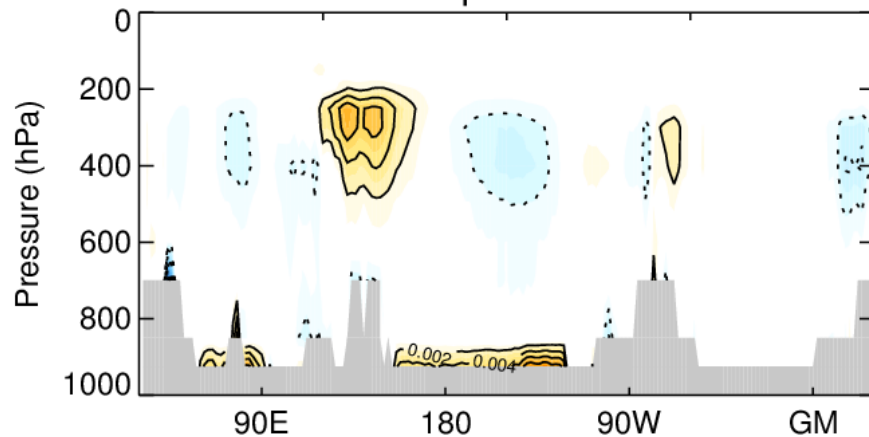


$$-\left(\frac{\partial\theta}{\partial P}\right)_p^{-1}\omega_p\Delta\left(\frac{\partial\theta}{\partial P}\right)$$

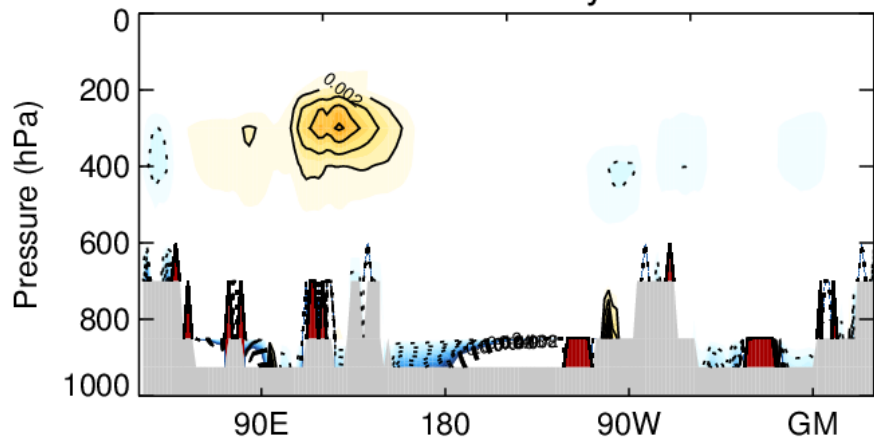
Stability component difference



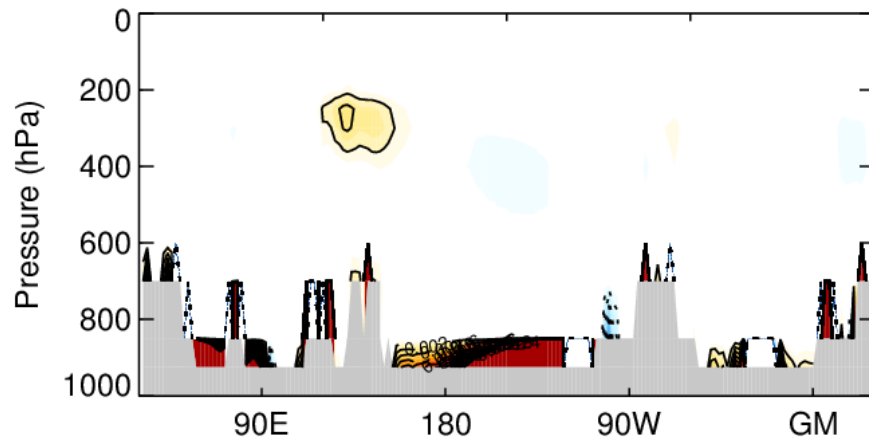
Difference in past clim influence



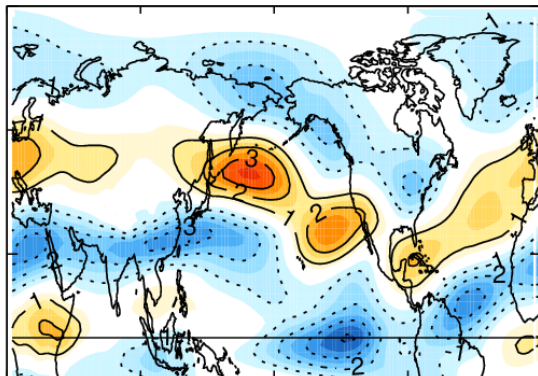
Difference in Stability influence



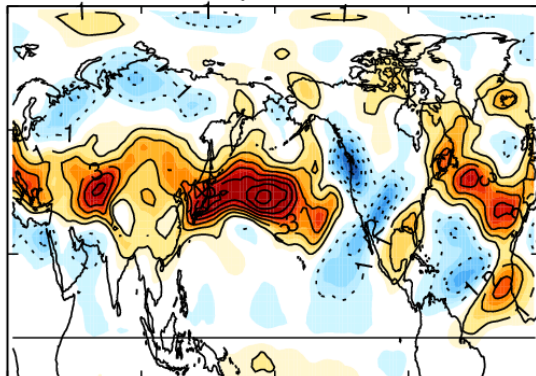
Nonlin



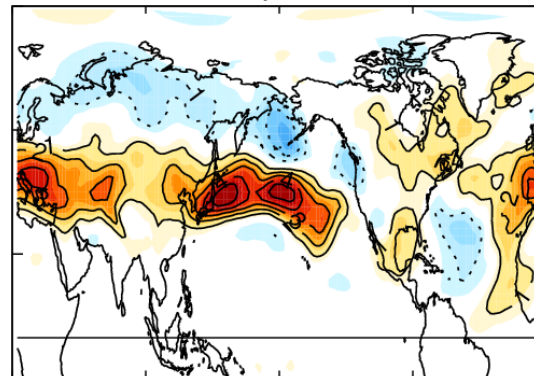
U, Poleward



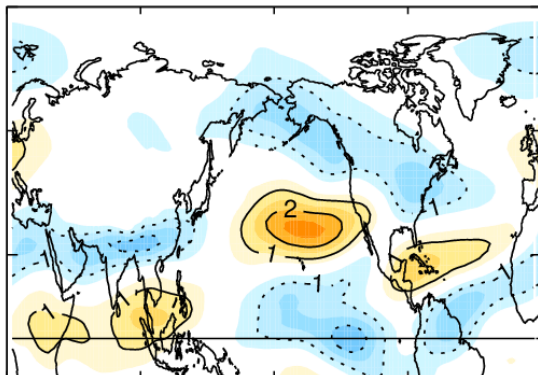
UV, poleward



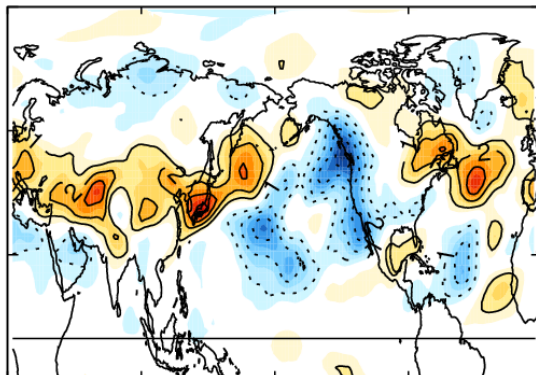
UhVh, poleward



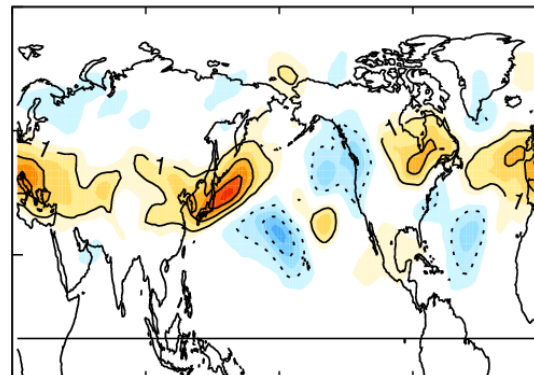
U, Not Poleward



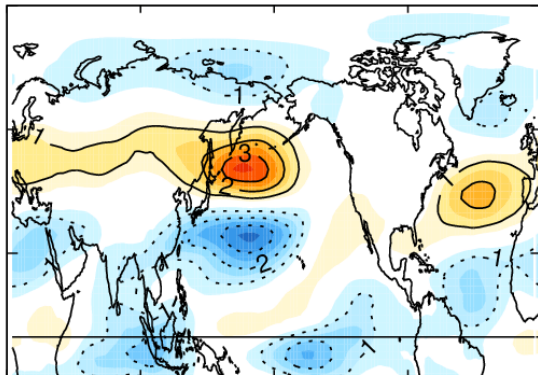
UV, Not Poleward



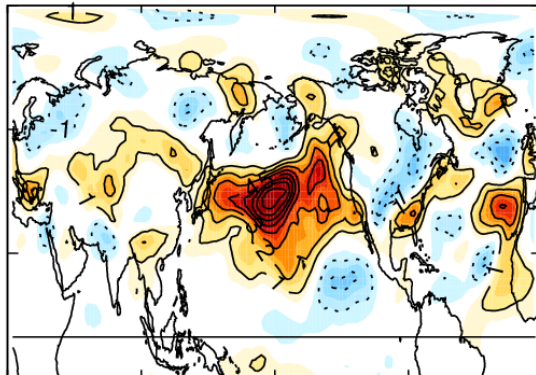
UhVh, Not Poleward



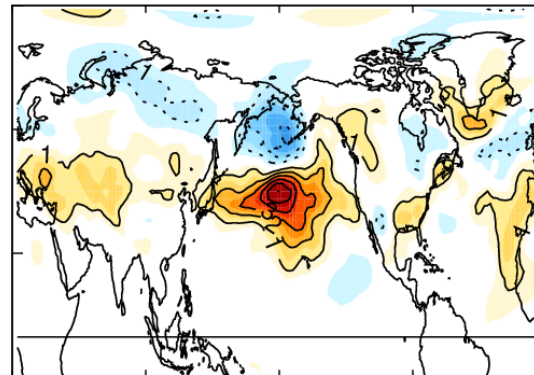
U, Poleward - Not Poleward



UV, Poleward - Not Poleward



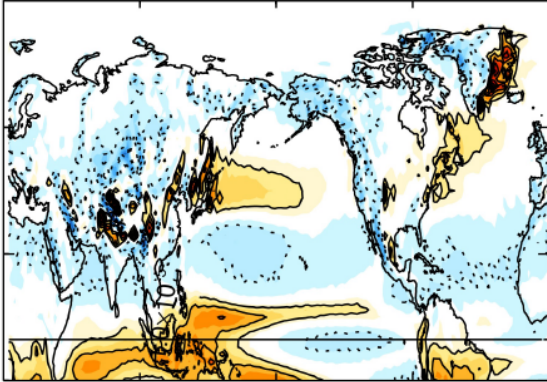
UhVh, Poleward - Not Poleward



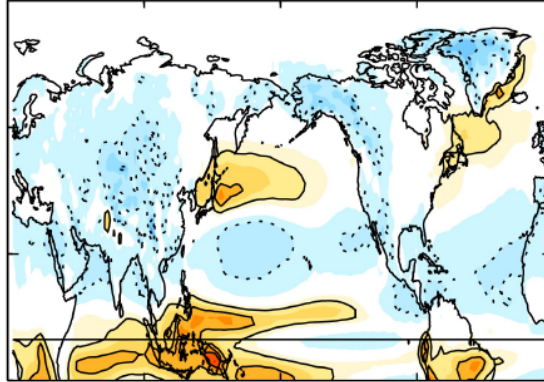


Vertically integrated diabatic heating  
(top) past, (bottom) future-past

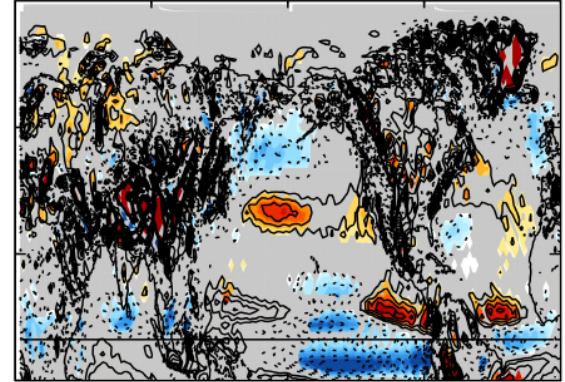
Positive, past



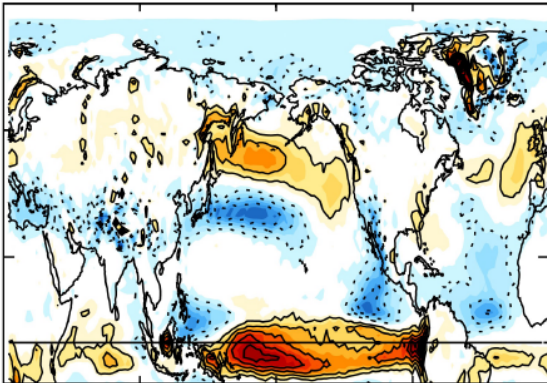
Negative, past



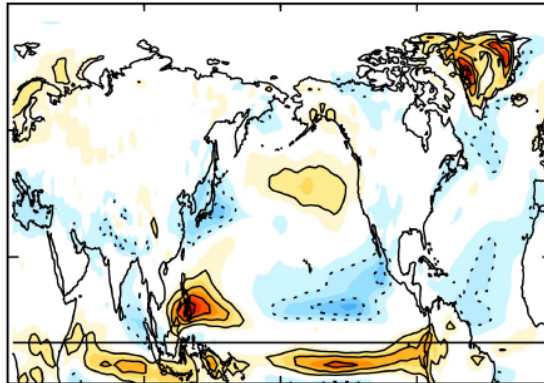
Positive-Negative, past



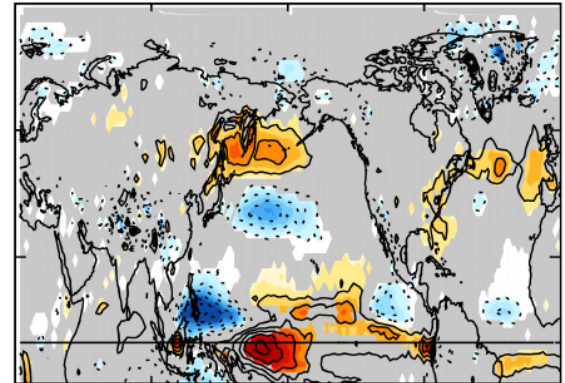
Positive, difference



Negative, difference



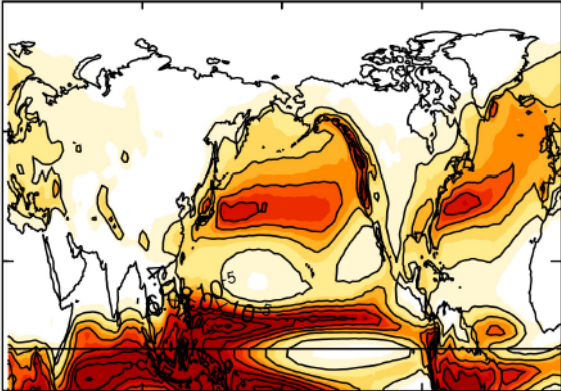
Positive-Negative, difference



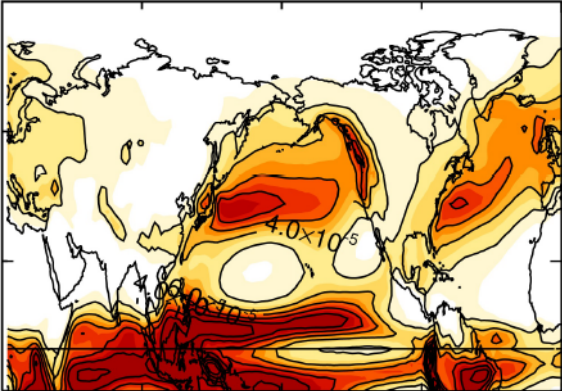


# Precipitation (top) past, (bottom) future-past

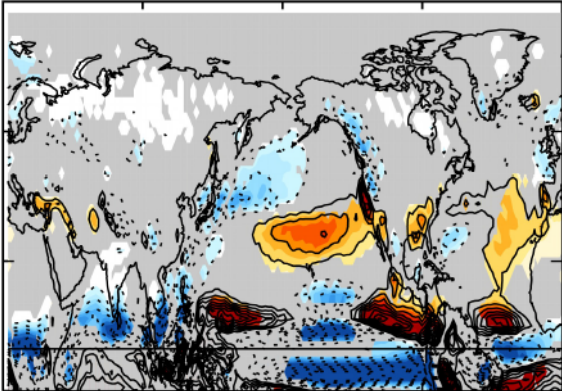
Positive EOF1, past



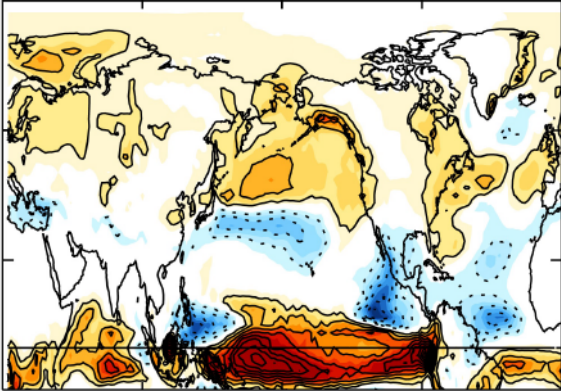
Negative EOF1, past



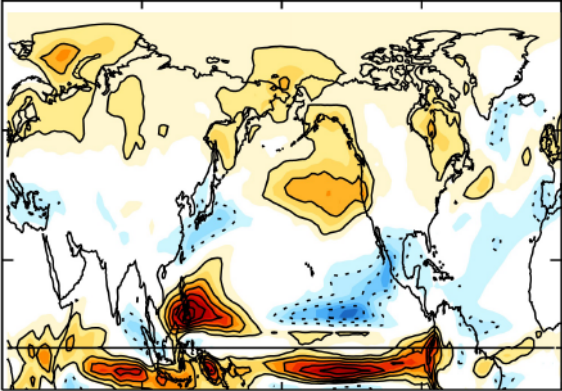
Positive-Negative EOF1, past



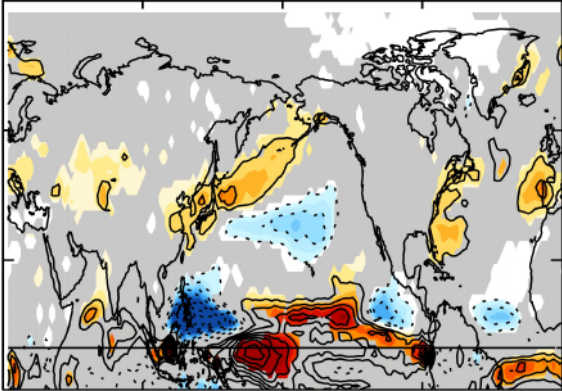
Positive EOF1, difference



Negative EOF1, difference

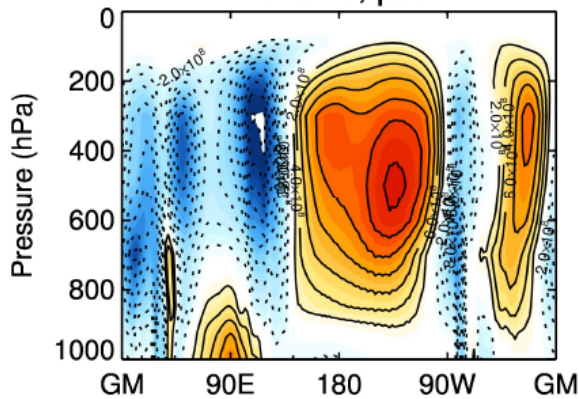


Positive-Negative EOF1, difference

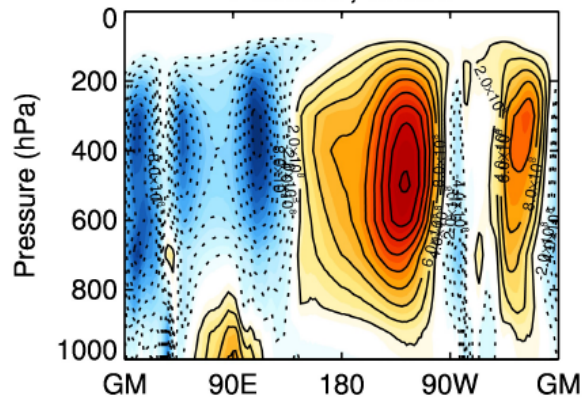


# Stream function (top) Past, (bottom) Future-Past

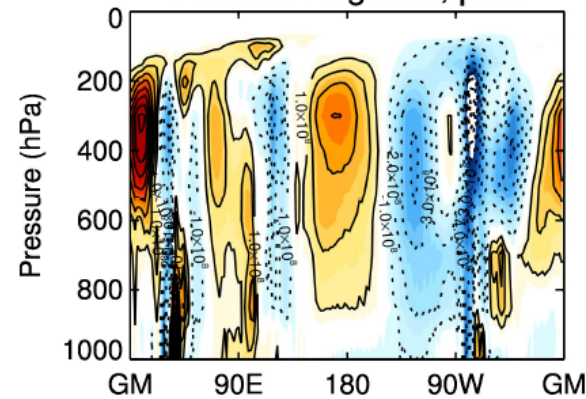
### Positive, past



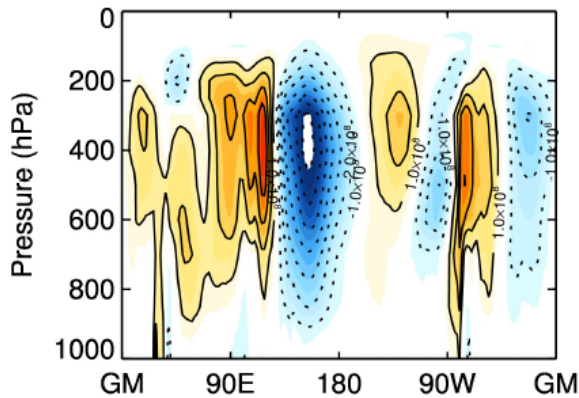
### Positive, future



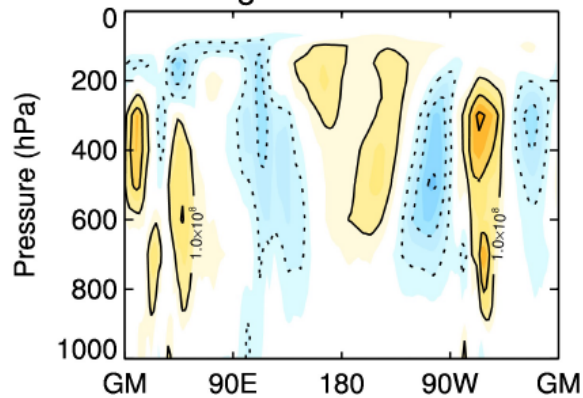
### Positive-Negative, past



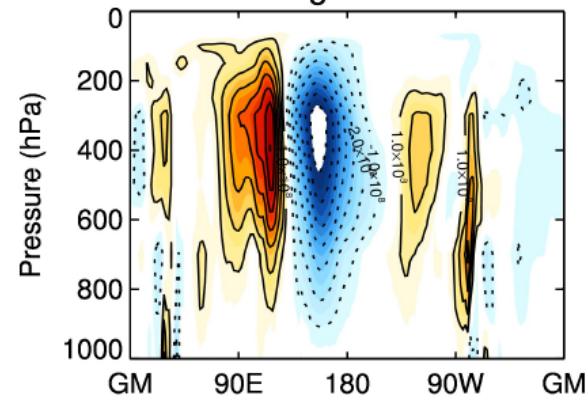
### Positive difference



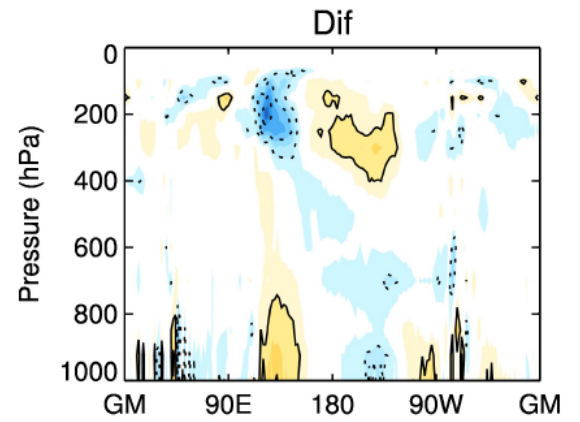
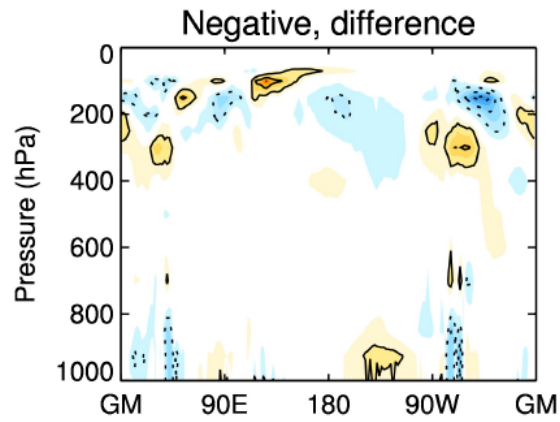
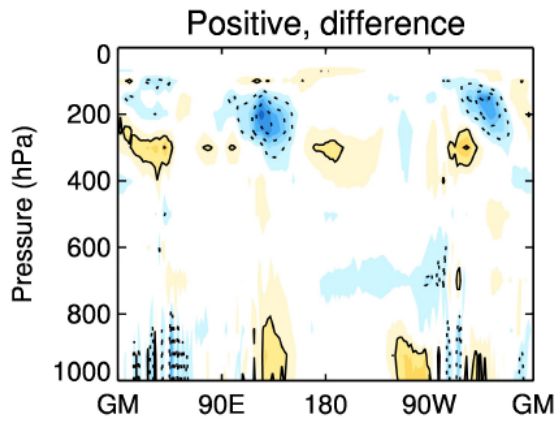
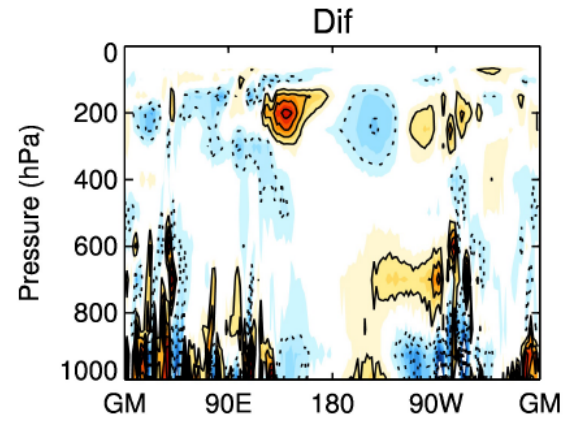
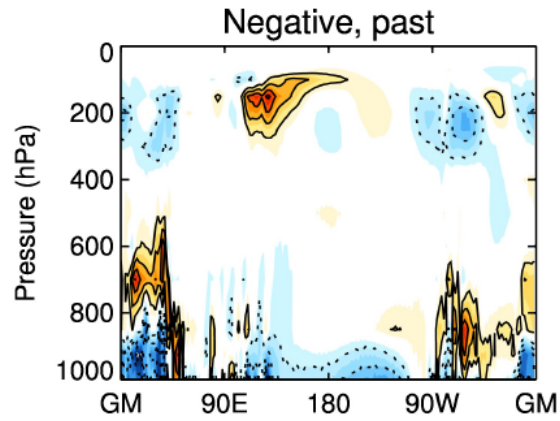
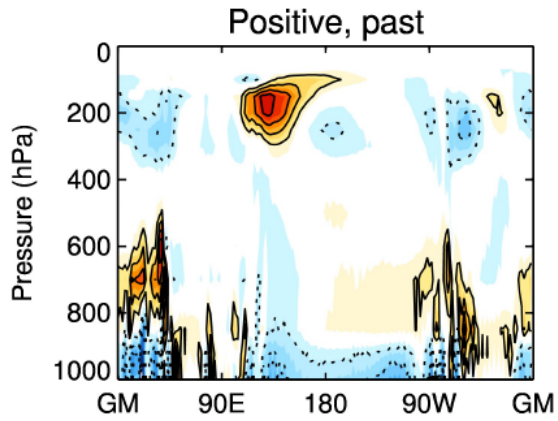
### Negative difference



### Positive-Negative difference

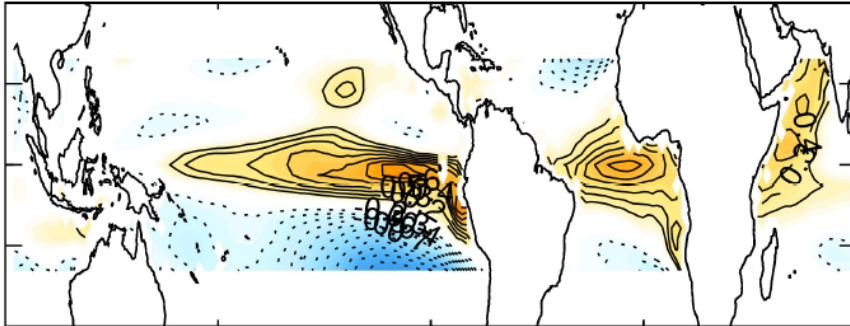


# Divergence (top) Past, (bottom) Future-past

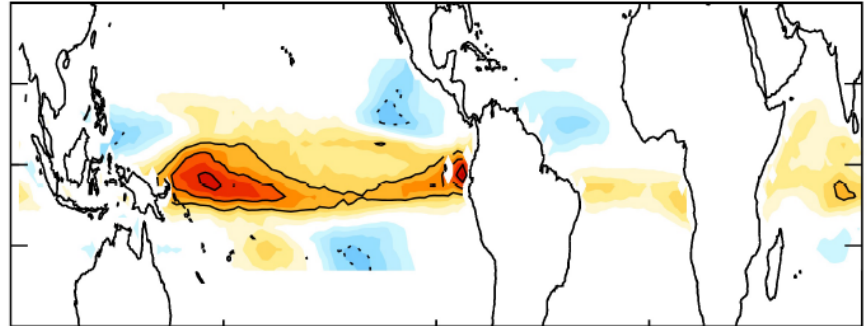




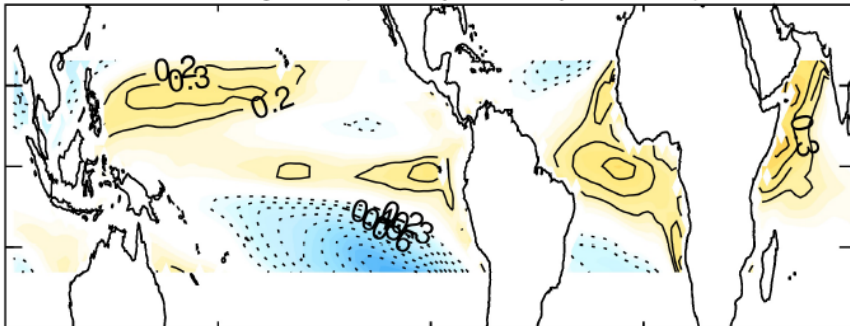
SST, positive (anomaly from tropical mean)



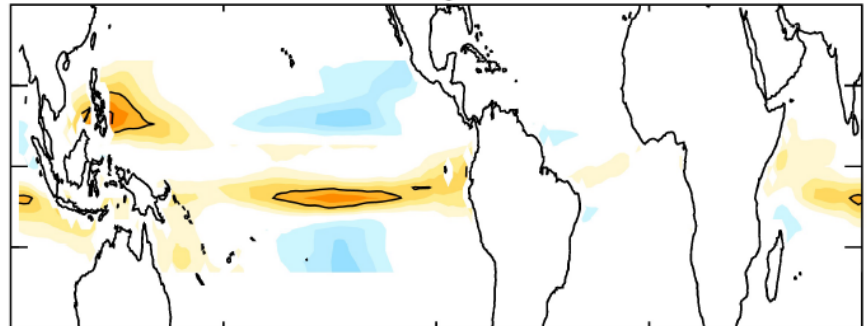
PR, Positive



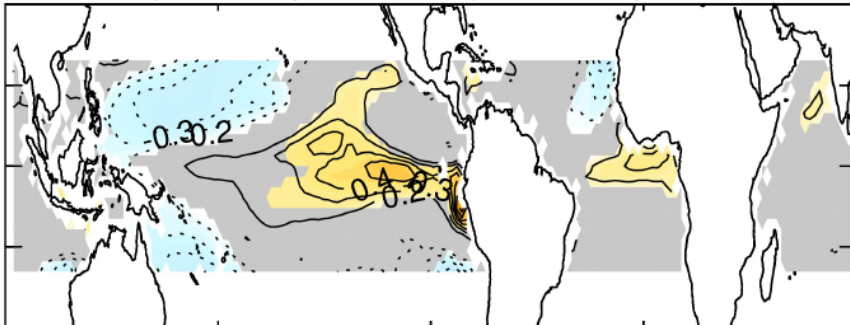
SST, negative (anomaly from tropical mean)



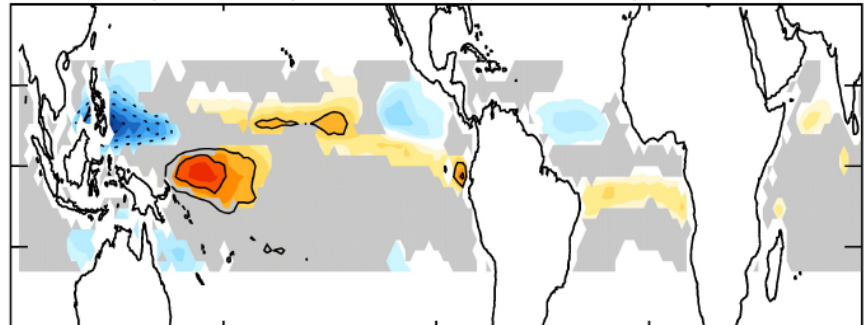
PR, negative



SST, positive-negative (anomaly from the tropical mean)

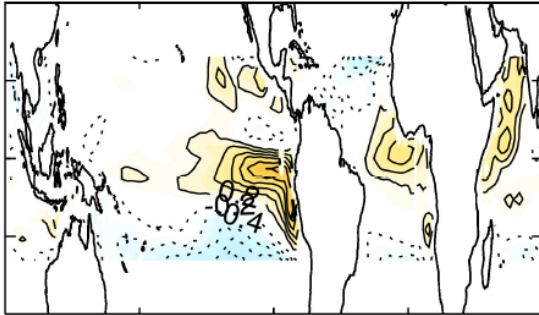


PR, positive-negative (anomaly from the tropical mean)

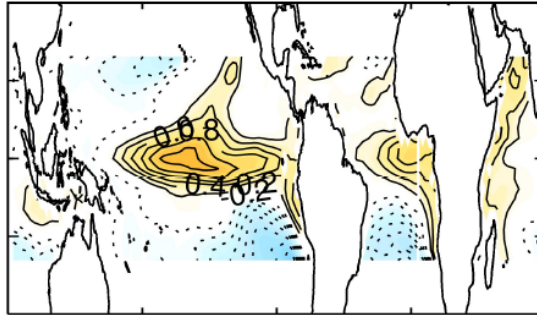


# SST response, anomalies from the tropical mean, Poleward models.

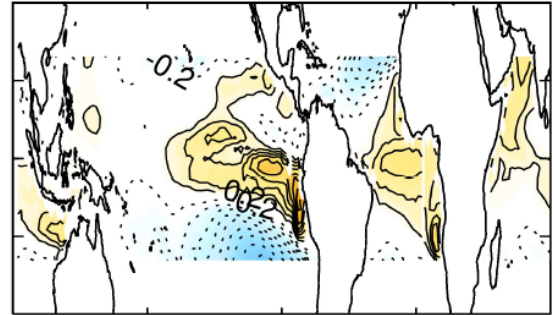
SST, MPI-ESM-LR



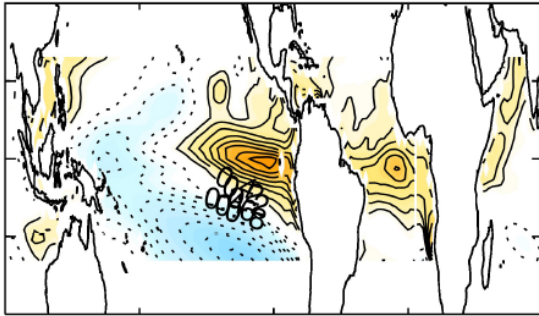
SST, MRI-CGCM3



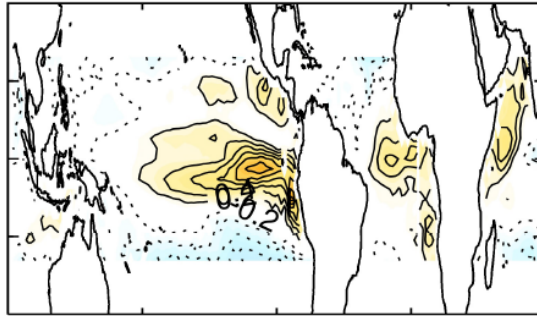
SST, CMCC-CMS



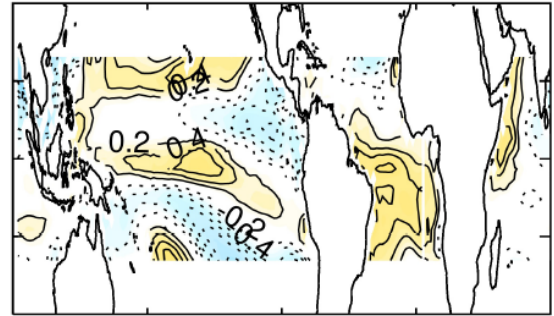
SST, MIROC5



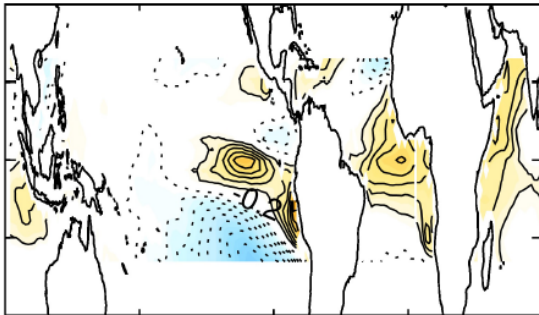
SST, MPI-ESM-MR



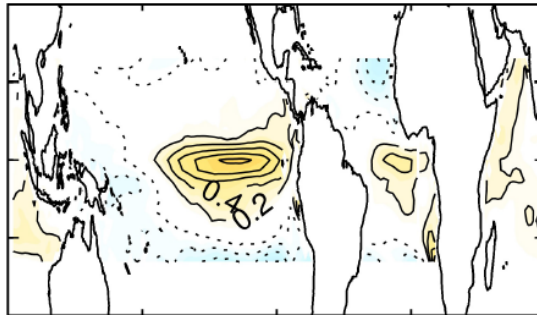
SST, IPSL-CM5A-MR



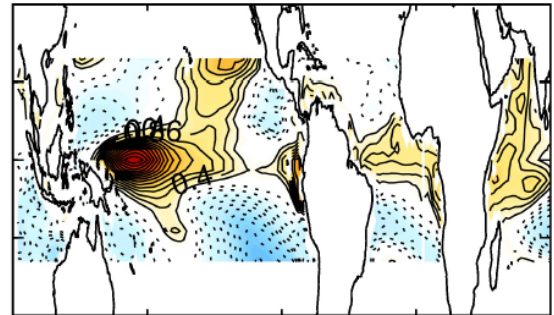
SST, CMCC-CM



SST, GISS-E2-R

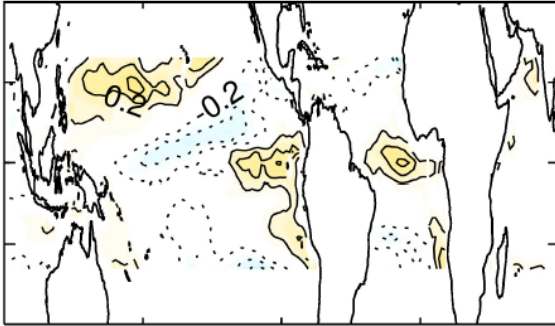


SST, CSIRO-Mk3-6-0

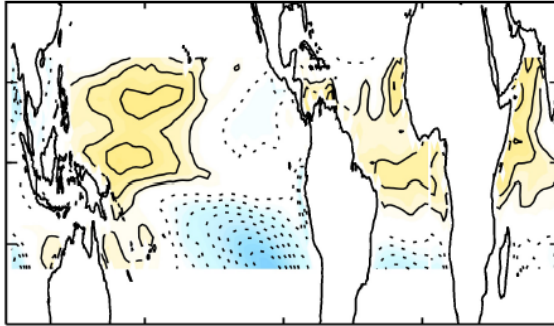


# SST response, anomalies from the tropical mean, Poleward models.

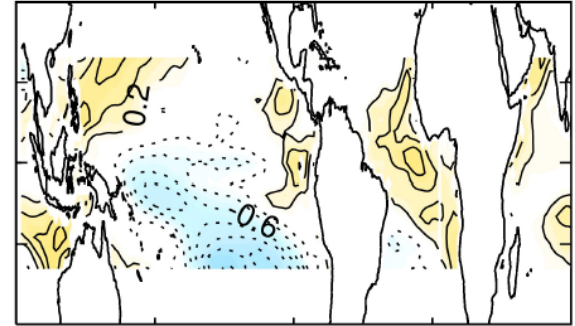
SST, Inmcm4



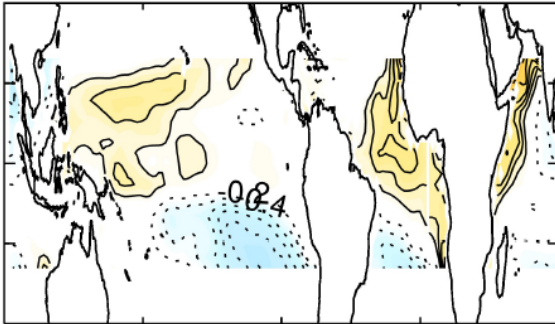
SST, GFDL-ESM2M



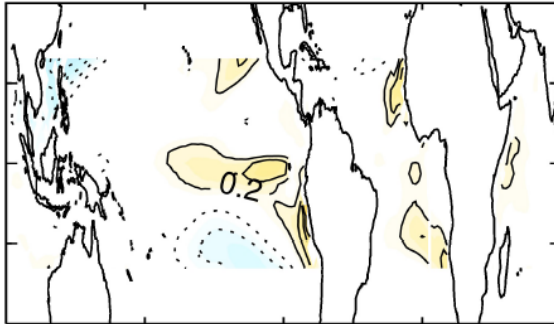
SST, NorESM1-ME



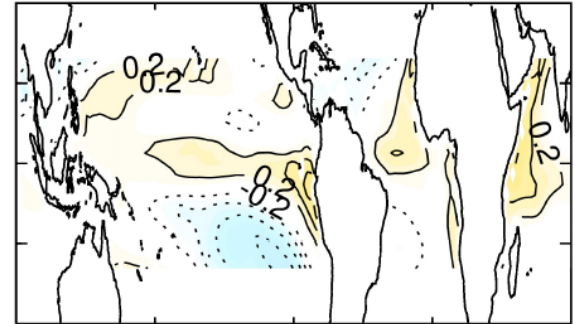
SST, BNU-ESM



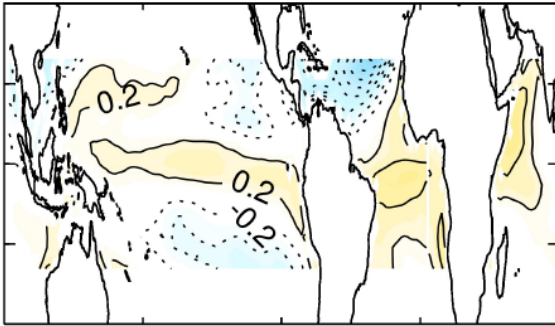
SST, CNRM-CM5



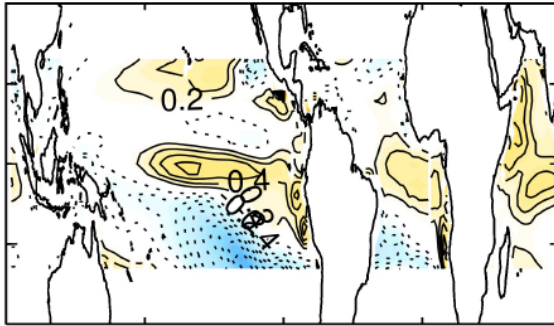
SST, CCSM4



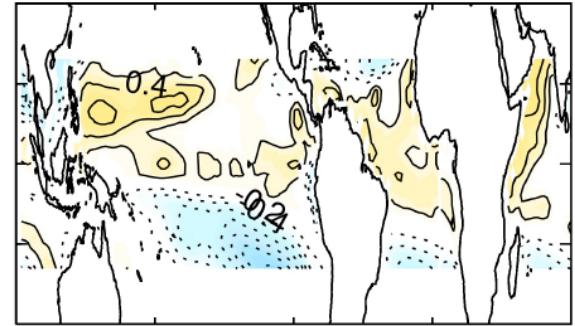
SST, FIO-ESM



SST, CanESM2



SST, GFDL-ESM2G









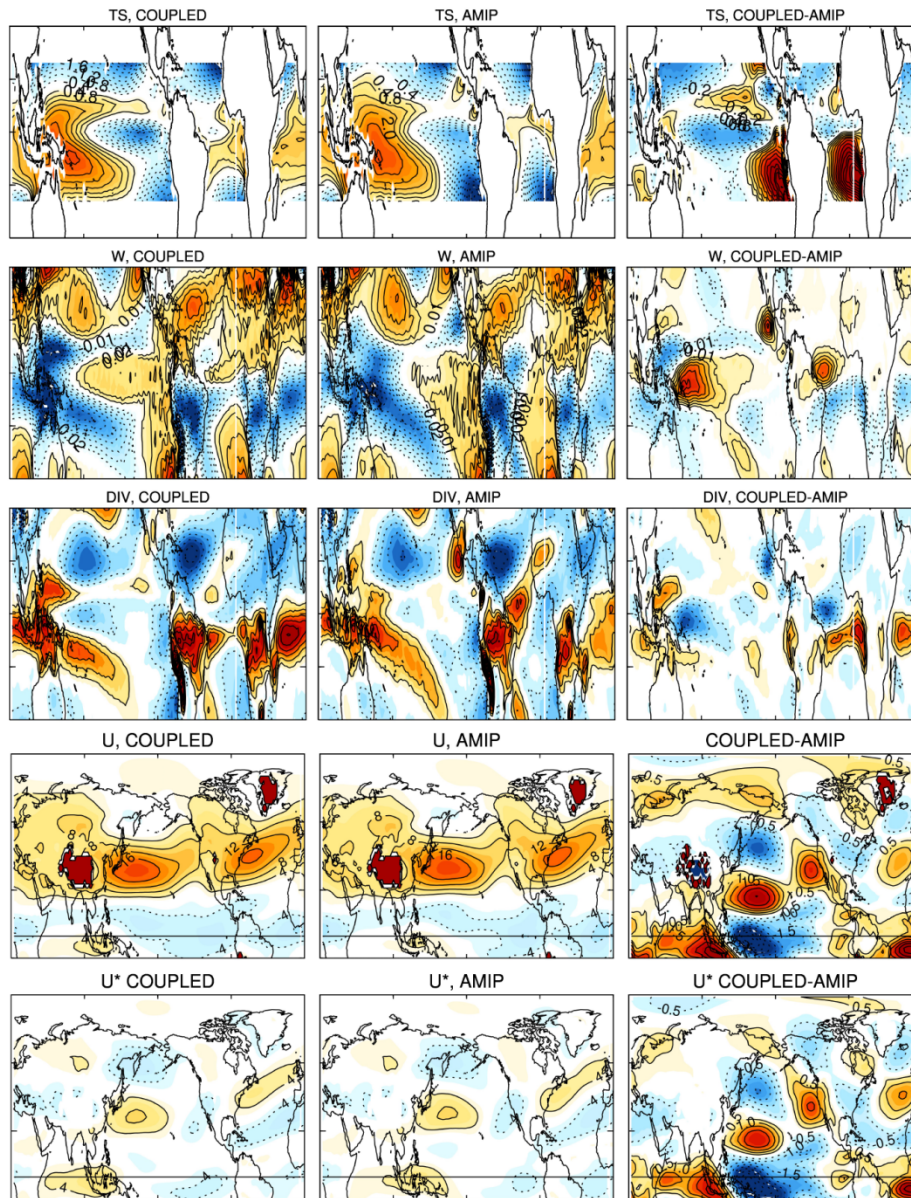


Figure 40: For the average of four models positive models (MPI-ESM-LR, MPI-ESM-MR, MIROC5, MRI-CGCM3) comparing the AMIP climatology with the coupled climatology (top) sst anomaly from the tropical mean, (2nd) 500hPa omega, (3rd) 250hPa divergence, (4th) 700hPa zonal wind, (5th) 700hPa eddy zonal wind.

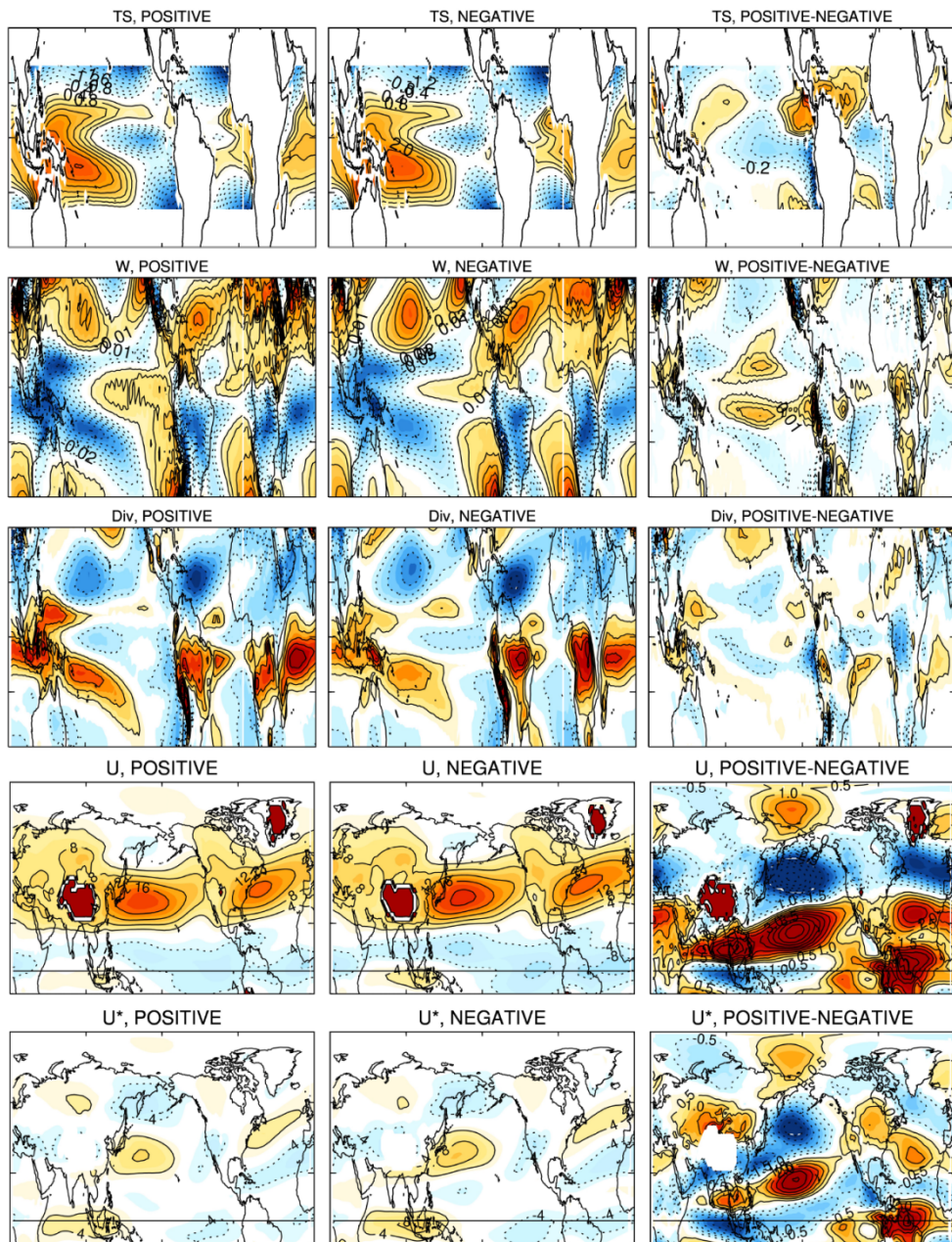
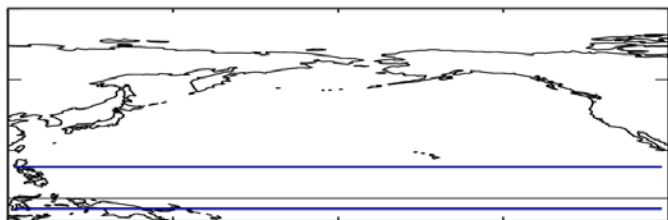
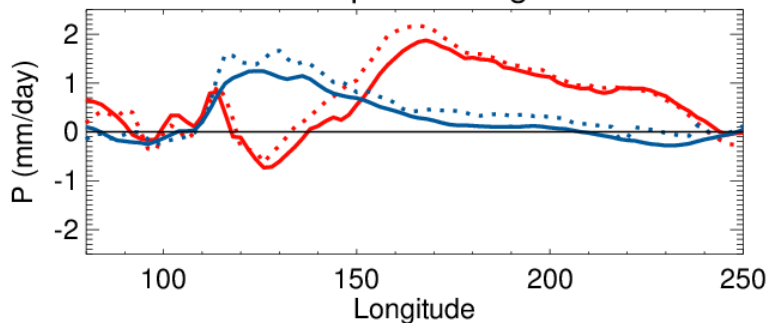


Figure 41: As Fig. 40 but for the positive and negative model composites (for comparison with Fig. 40)

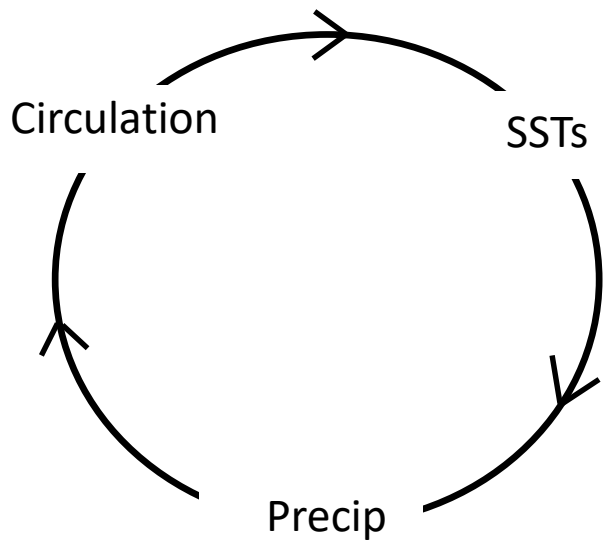


Precip and Budget



— Not Poleward    — Poleward

Dotted = sum of terms

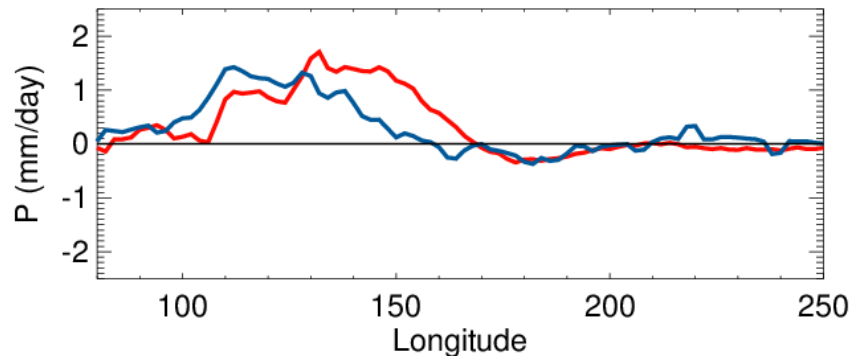


$$\Delta P = \Delta E - \int_{p_s}^0 \nabla \cdot (\Delta \vec{v} q) dp - \int_{p_s}^0 \nabla \cdot (\vec{v} \Delta q) dp$$

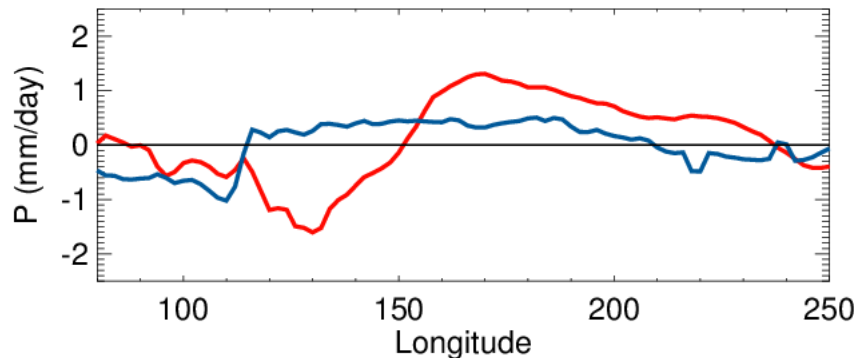
Change in circulation

Change in moisture

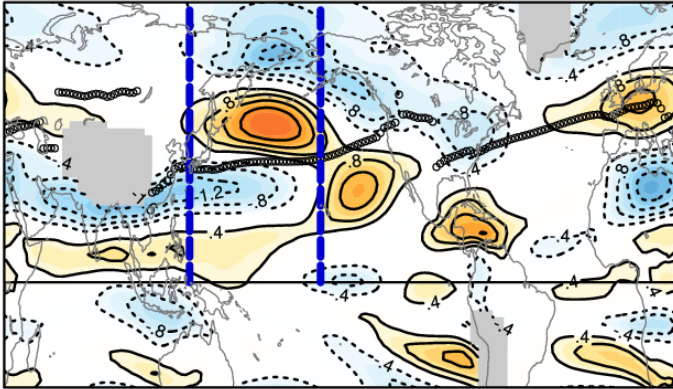
Moisture effect



Circulation effect







# 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)

