Towards understanding intermodel spread in the circulation response to ozone depletion/recovery

Chaim I. Garfinkel, Ian White, Martin Jucker, Ed Gerber, Seok-Woo Son

Garfinkel, C. I., I. White, E. P. Gerber, S. Son, and M. Jucker, 2023: Stationary Waves Weaken and Delay the Near-Surface Response to Stratospheric Ozone Depletion. *J. Climate*, **36**, 565–583, https://doi.org/10.1175/JCLI-D-21-0874.1.

Waugh, D. W., C. I. Garfinkel, and L. M. Polvani, 2015: Drivers of the Recent Tropical Expansion in the Southern Hemisphere: Changing SSTs or Ozone Depletion?. *J. Climate*, **28**, 6581–6586, https://doi.org/10.1175/JCLI-D-15-0138.1.

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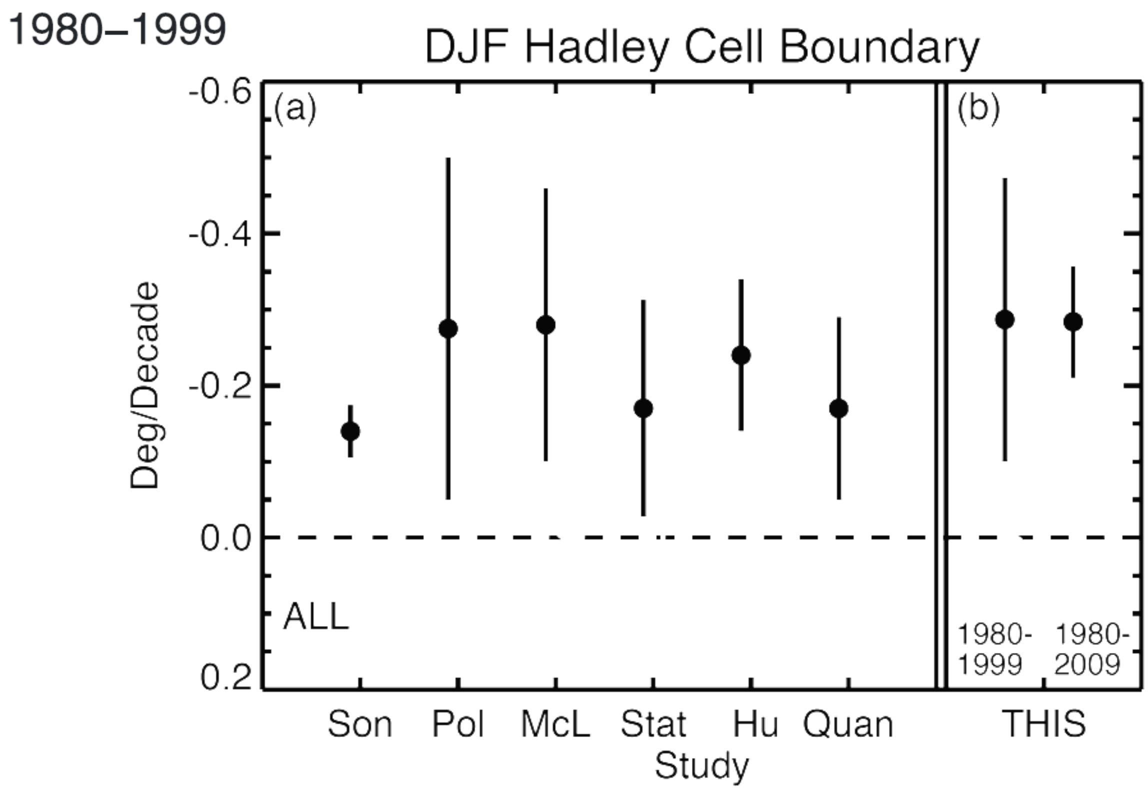
Trends in Hadley Cell Boundary: ALL Forcing

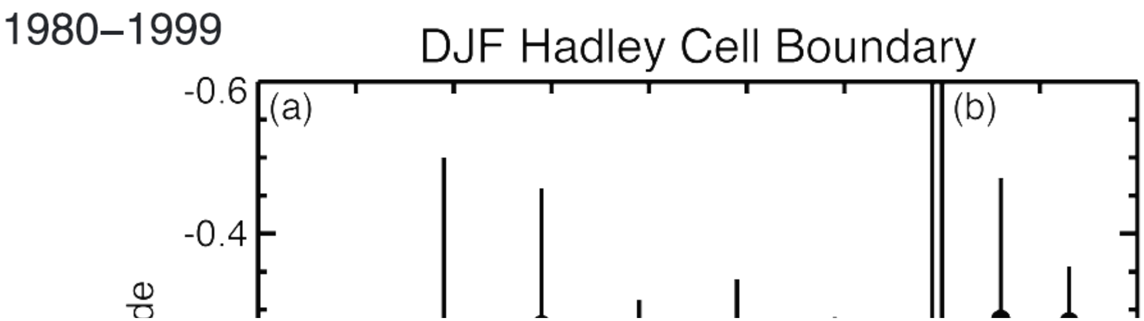


Reanalysis Trends

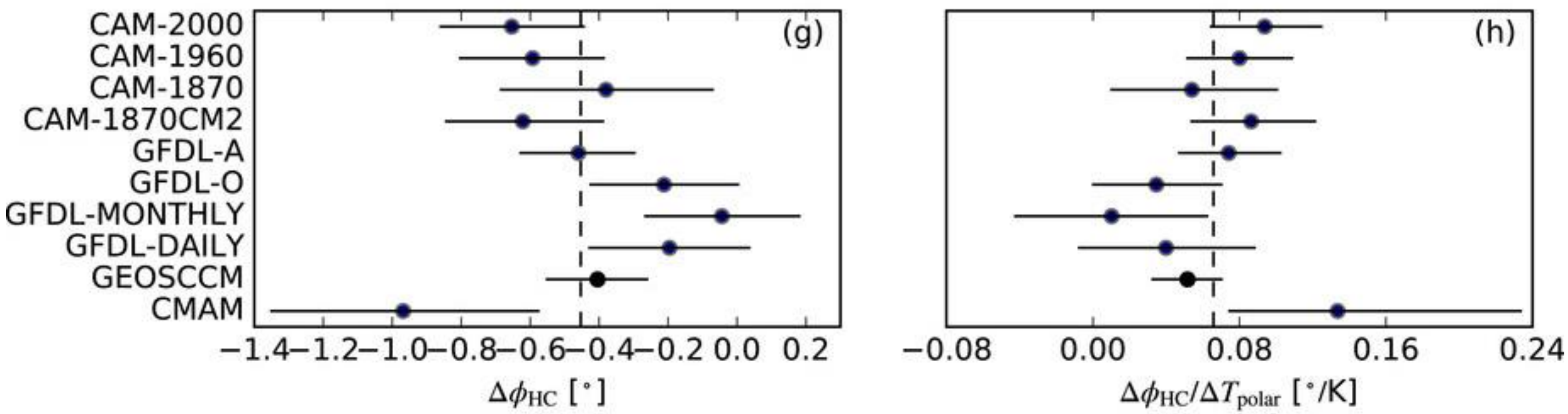
(Waugh et al. 2015)

- Significant trends for all studies but with spread in magnitude
- While ensemble mean trend less than observed, individual members simulate trends as strong as observed (Garfinkel et al 2015).

Trends in Hadley Cell Boundary: ALL Forcing



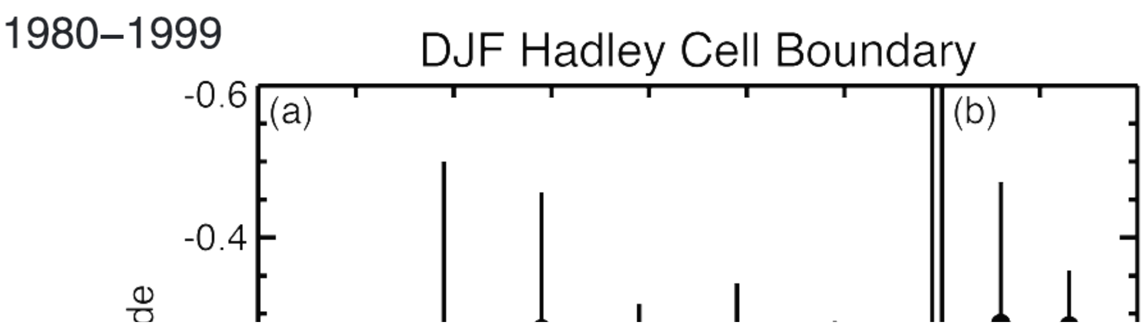
Reanalysis
Trends



- Significant for all studies, although with substantial spread not explained by polar stratospheric response itself.

(Seviour et al. 2017)

Trends in Hadley Cell Boundary: ALL Forcing



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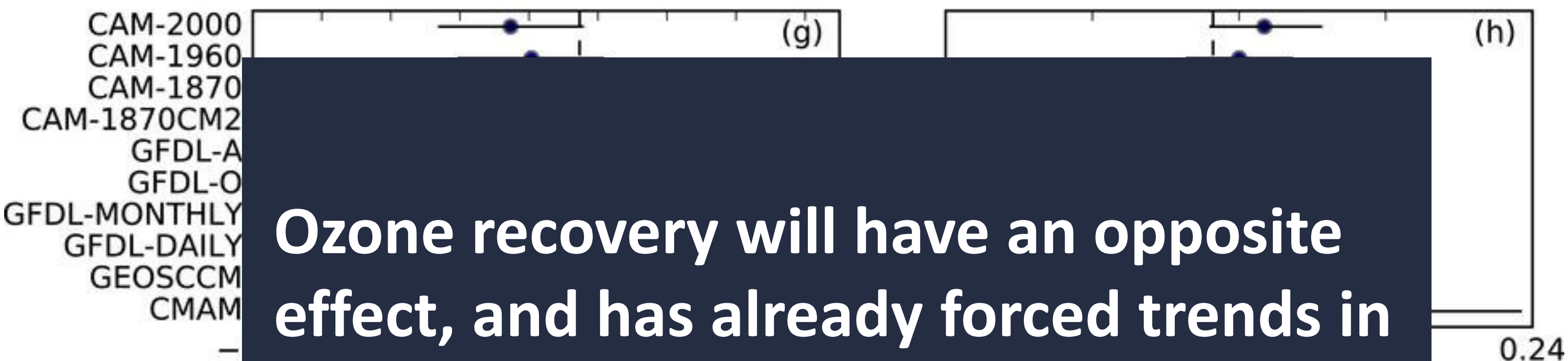

Ozone recovery will have an opposite effect, and has already forced trends in SH climate **[Banarjee et al 2020, Nature].**

What governs the intermodel spread in the magnitude?

- Significa… …pread not expl…

…017)

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What could influence the magnitude of the downward impact of ozone depletion/recovery?

1) The ozone dataset used to force a model [Neely et al. 2014; Young et al. 2014; Seviour et al 2017] and jet latitude [Garfinkel et al. 2013; Simpson and Polvani 2016; Son et al 2018]

But there are more we are just beginning to reveal!

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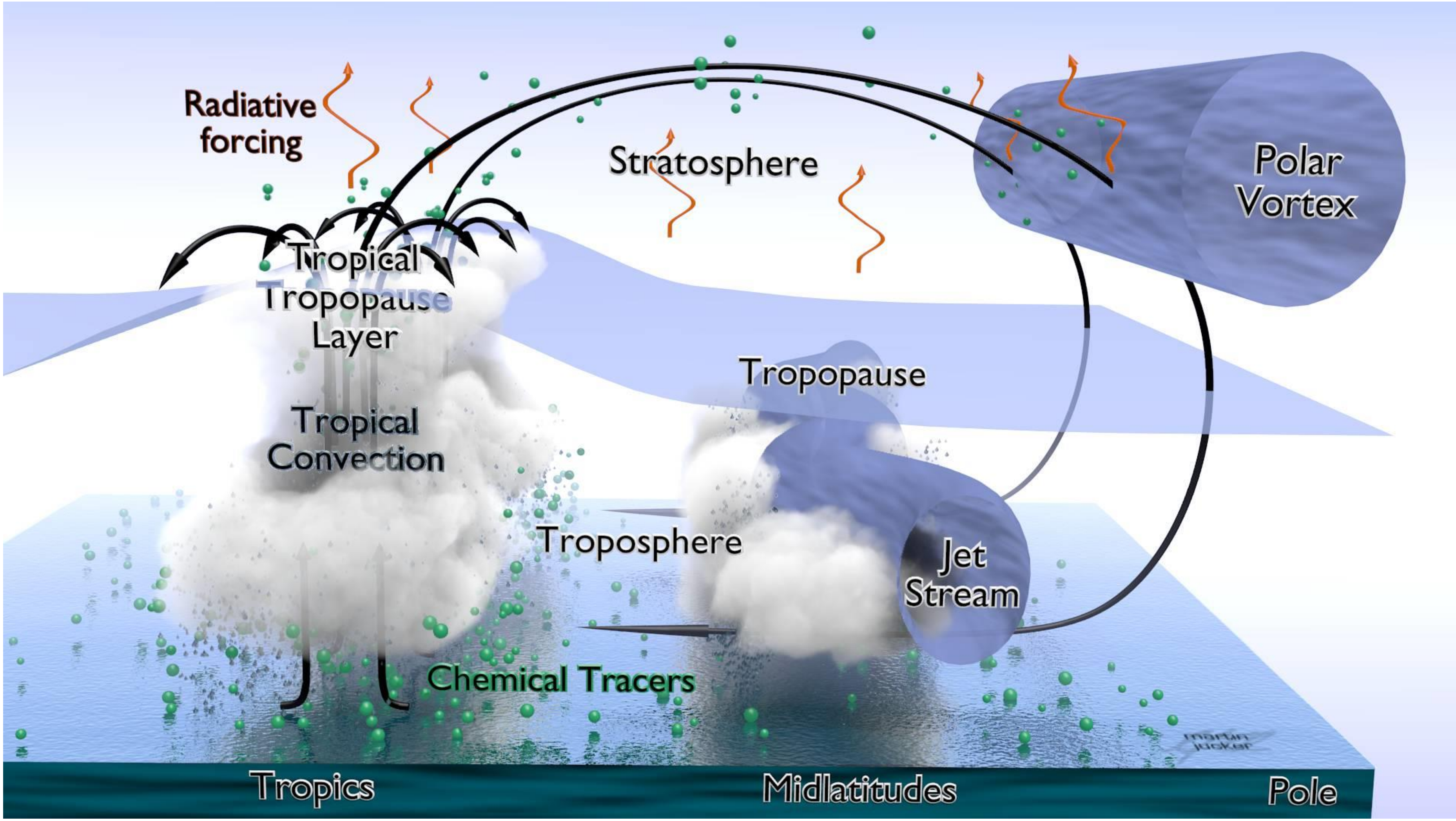
Model of an idealized moist atmosphere



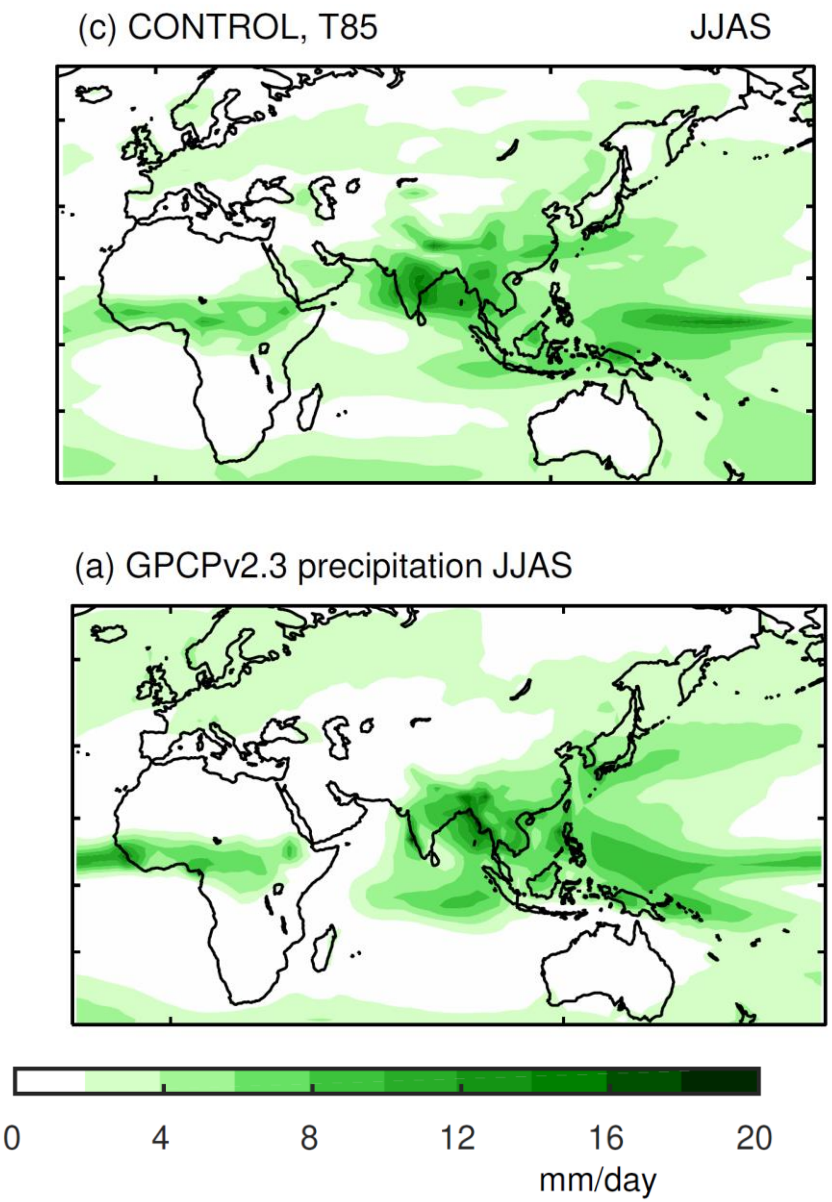
Primitive equations based moist aquaplanet GCM
Full radiation scheme (RRTMG). Moisture and convection.

Jucker and Gerber 2017
Frierson 2007

Realism of precip when all forcings included

CONTROL
(+east-west ocean heat fluxes, +land/sea contrast +topography)

GPCP



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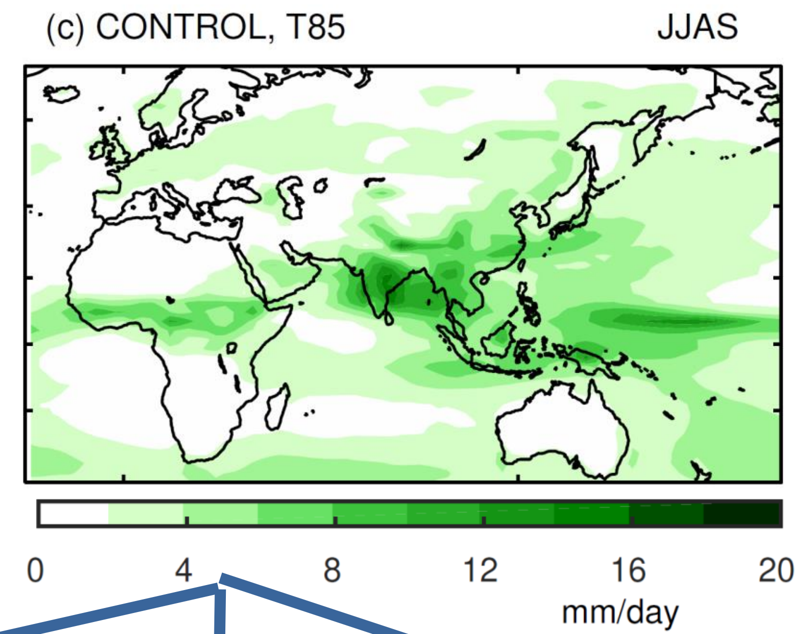
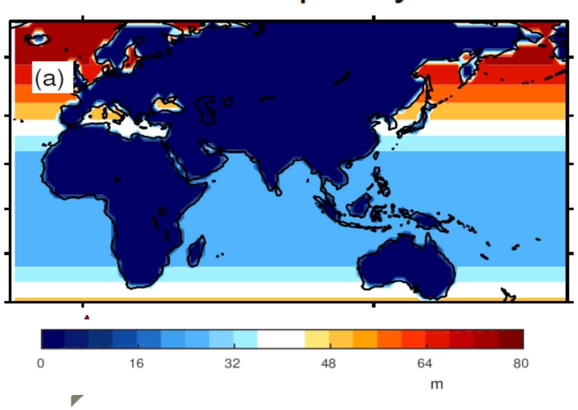
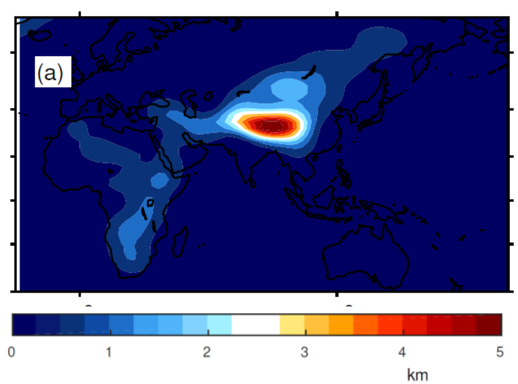


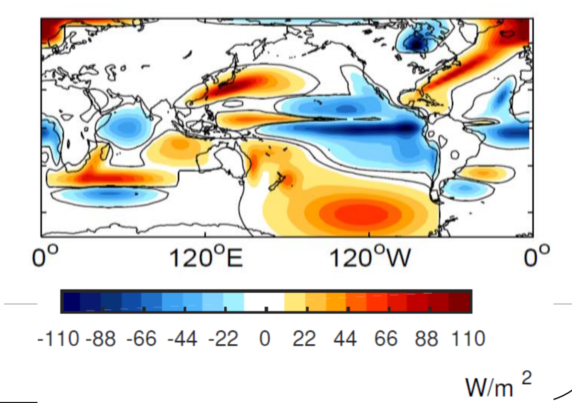
heat capacity



topography



east-west ocean-fluxes



Realism of precip when all forcings included

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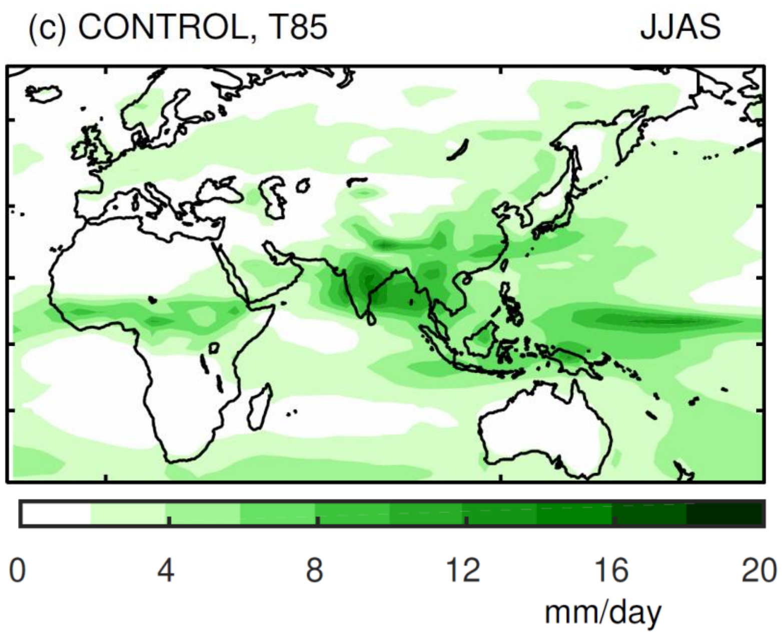
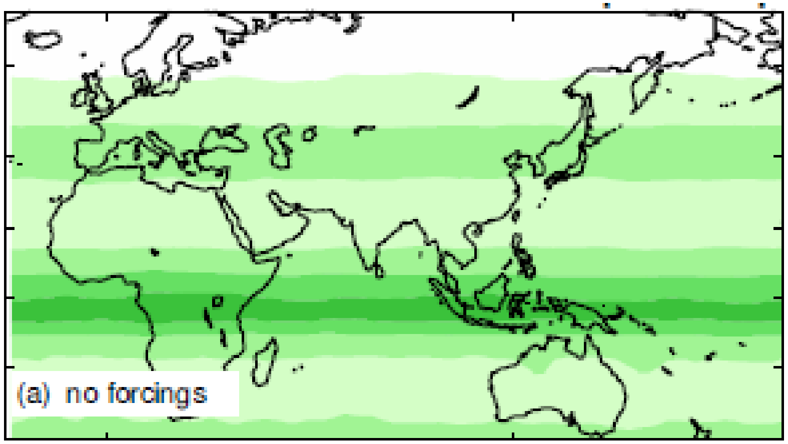
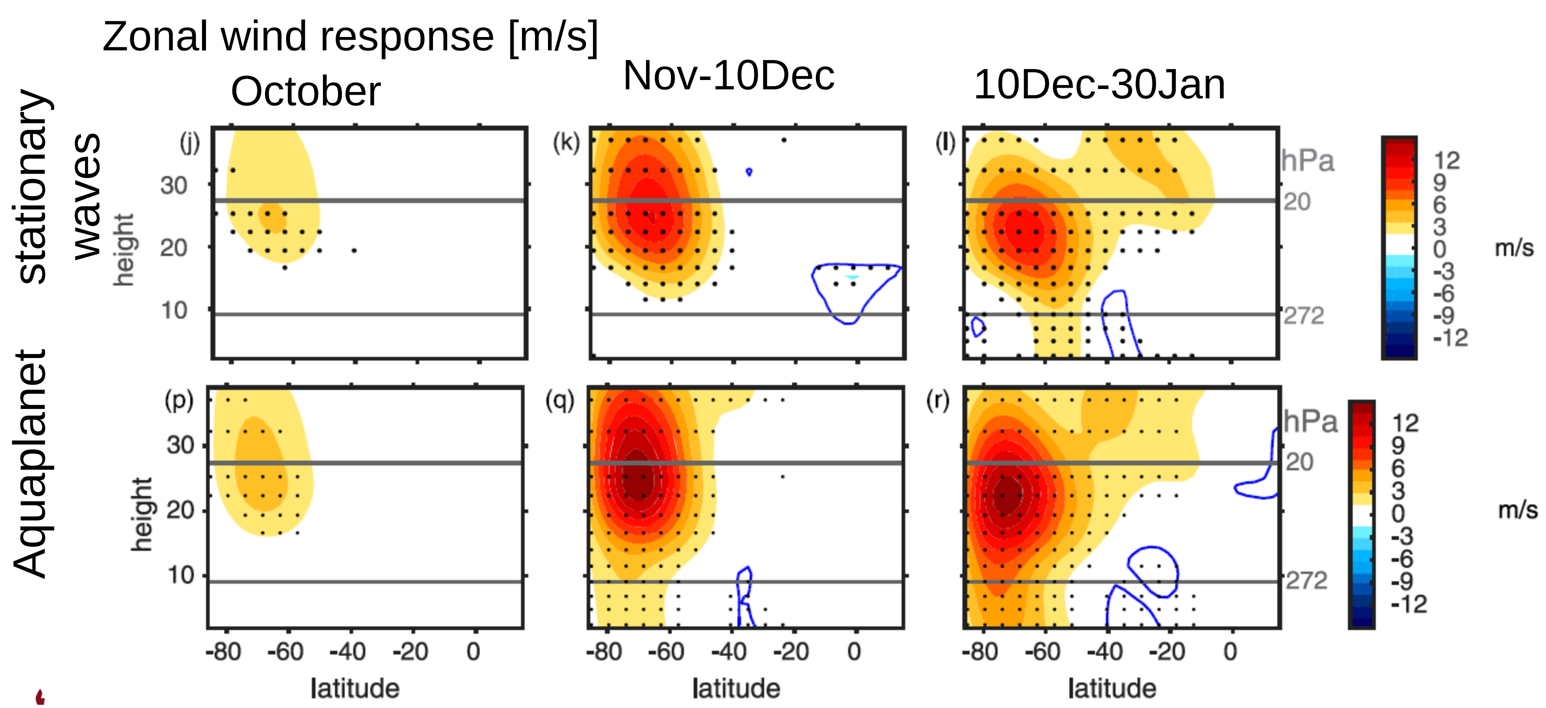


Aquaplanet
(zonally symmetric lower boundary)



What could influence the magnitude of the downward impact of ozone depletion/recovery?

1) The ozone dataset used to force a model [Neely et al. 2014; Young et al. 2014; Seviour et al 2017] and jet latitude [Garfinkel et al. 2013; Simpson and Polvani 2016; Son et al 2018]
2) Strength of stationary waves in a model [Garfinkel et al 2023]



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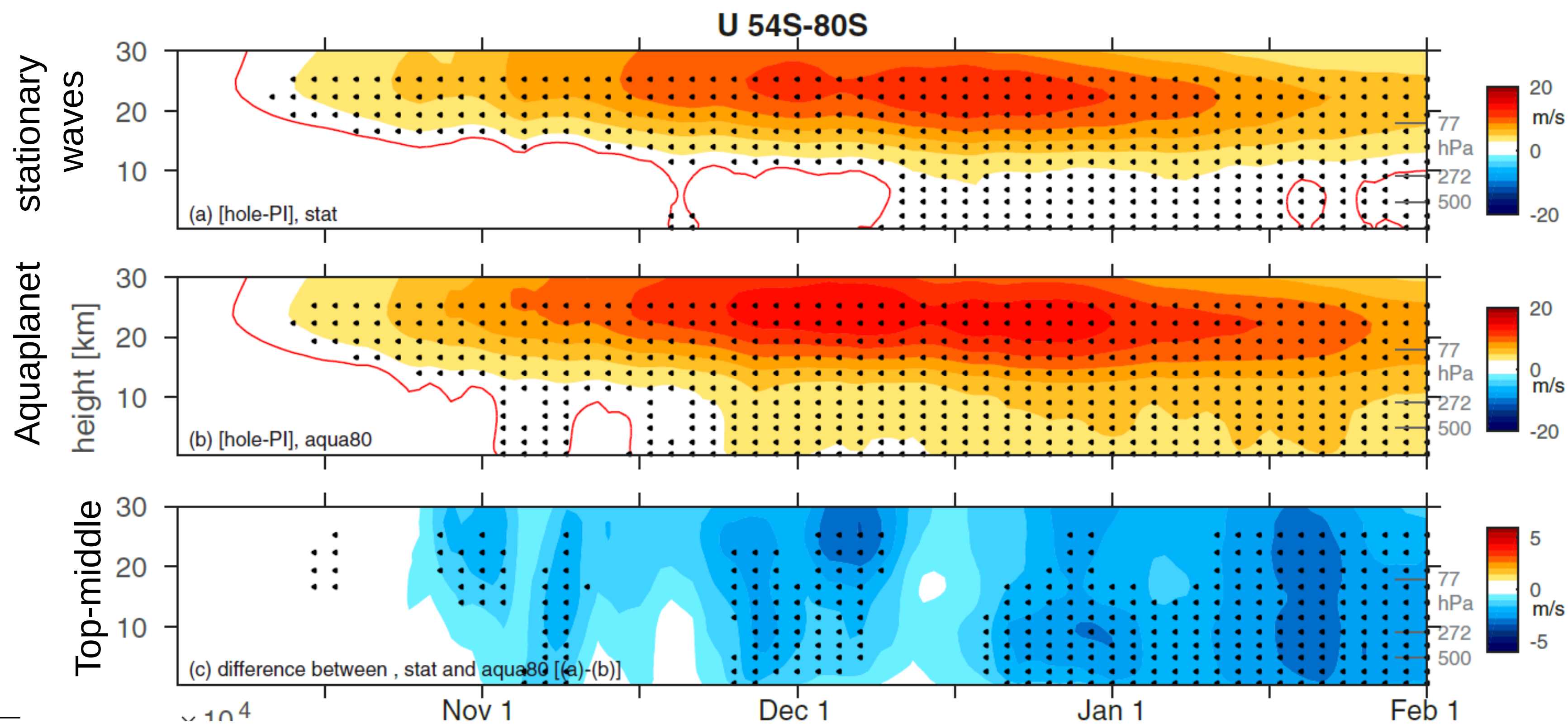

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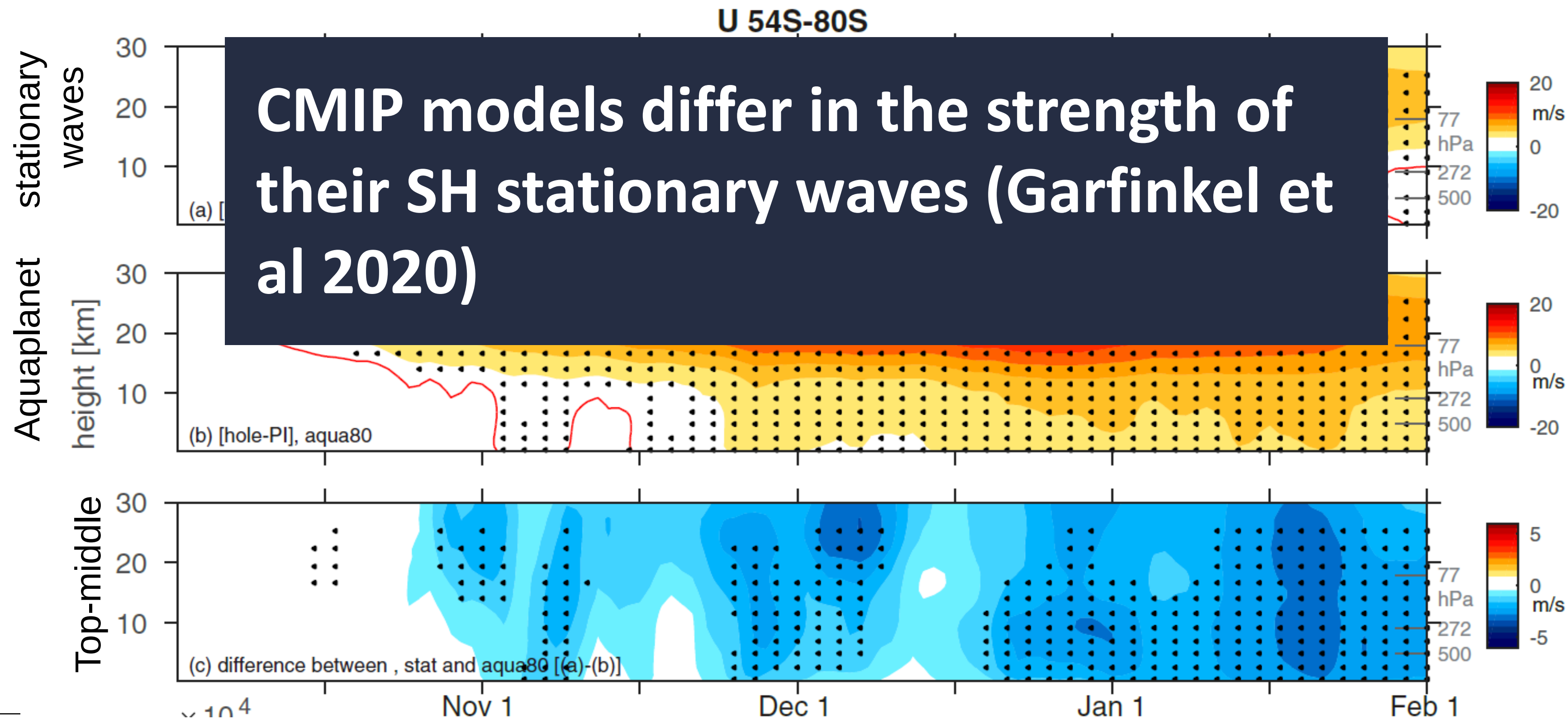
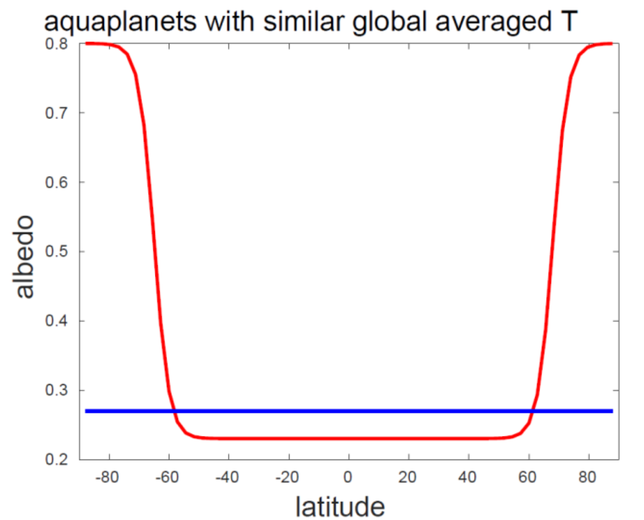


CMIP models differ in the strength of their SH stationary waves (Garfinkel et al 2020)

What could influence the magnitud impact of ozone depletion/



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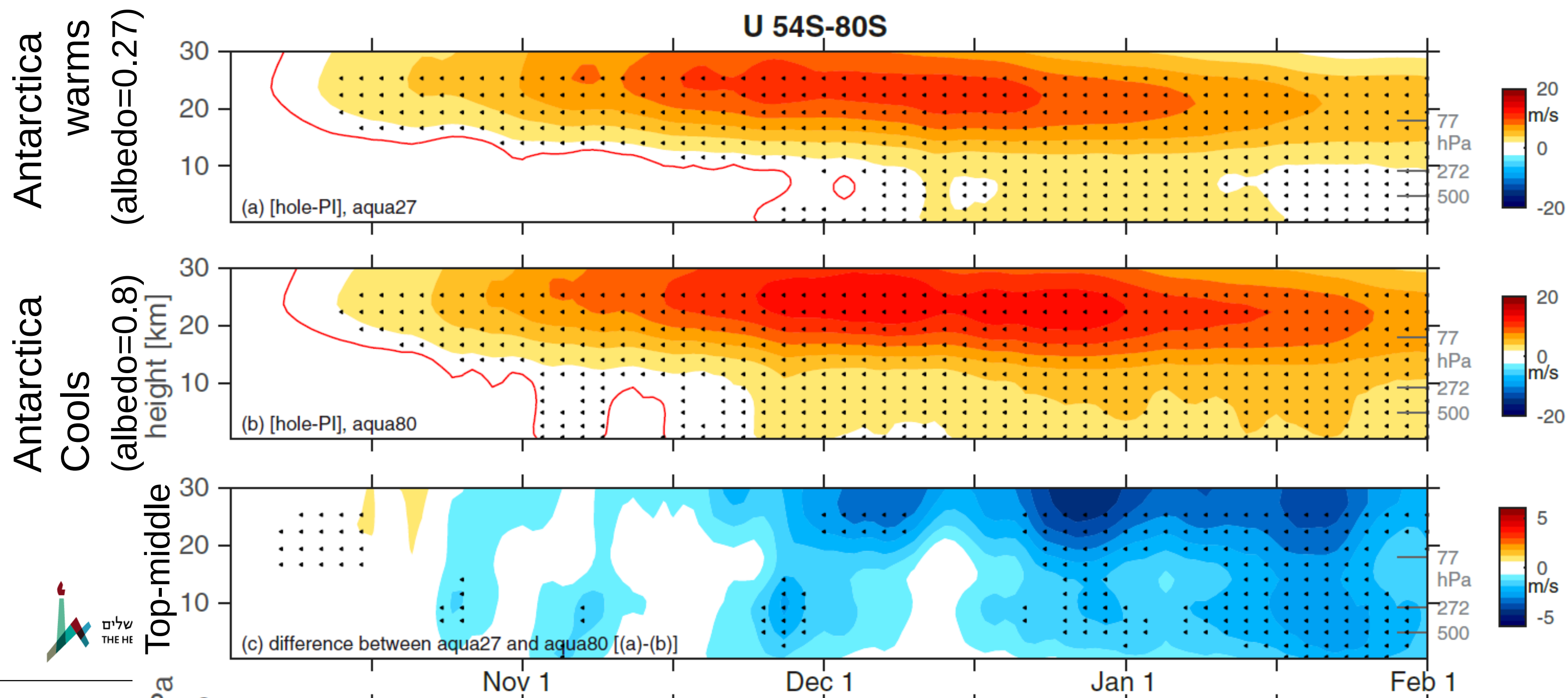
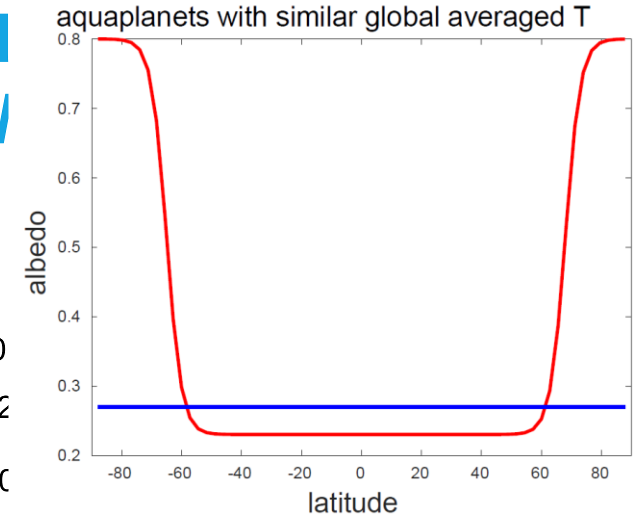
2) Strength of stationary waves in a model [Garfinkel et al 20
3) Antarctic surface temperature response in a model [Garfinkel et al 2023]



What could influence the magnitud… impact of ozone depletion/…



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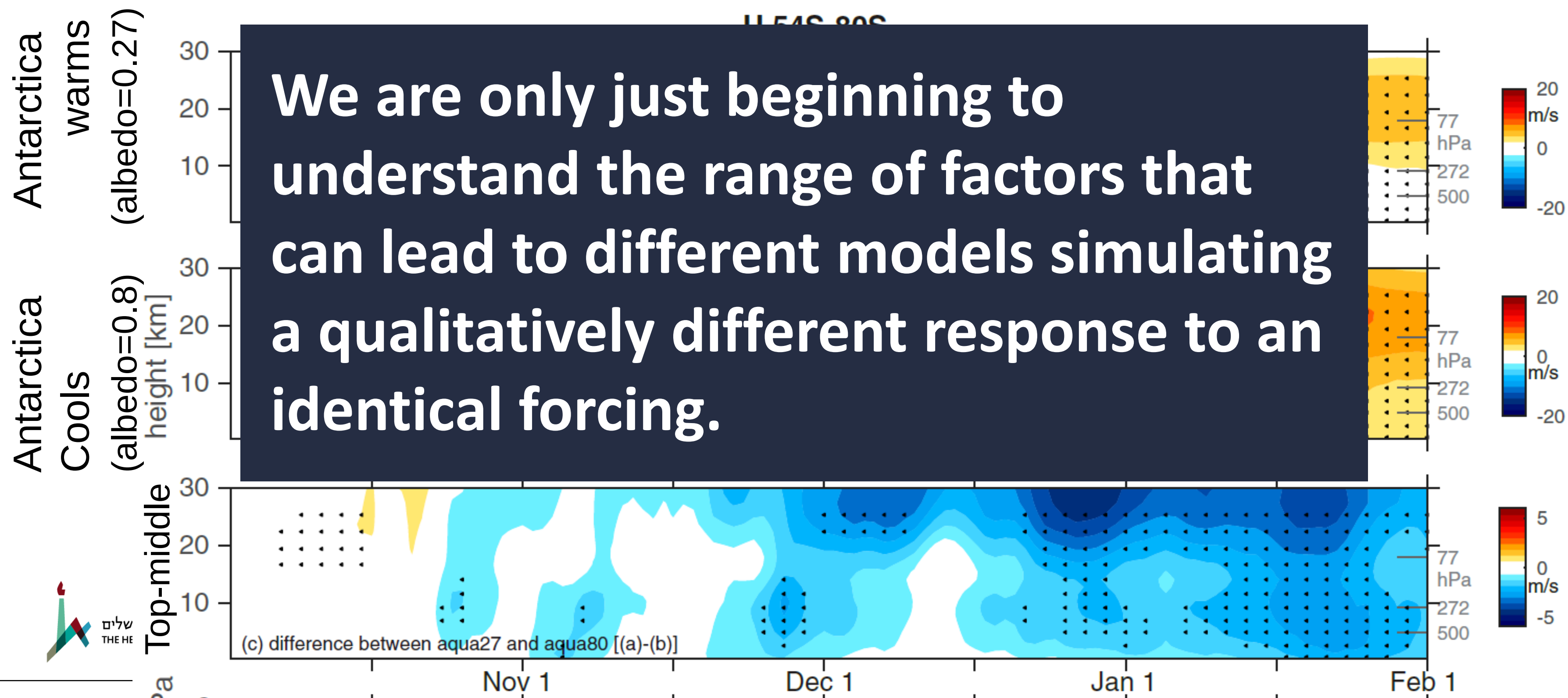

We are only just beginning to understand the range of factors that can lead to different models simulating a qualitatively different response to an identical forcing.

Conclusions:

At least four distinct processes may explain intermodel spread in the tropospheric response to ozone depletion.

We are only beginning to quantify their relative importance for intermodel spread in comprehensive models.

Two of the four were recently shown by Garfinkel et al 2023 to be important in targeted modeling experiments:

a. **Stationary waves** lead to a weaker stratospheric and tropospheric response to an identical ozone perturbation
b. **Cooling over Antarctica** enhances the stratospheric and tropospheric response to an identical ozone perturbation

Garfinkel, C. I., I. White, E. P. Gerber, S. Son, and M. Jucker, 2023: Stationary Waves Weaken and Delay the Near-Surface Response to Stratospheric Ozone Depletion. *J. Climate*, **36**, 565–583, https://doi.org/10.1175/JCLI-D-21-0874.1.

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Sensitivity of Future Circulation Changes to the Convective Parameterization

Chaim I. Garfinkel, Benny Keller, Orli Lachmy, Ian White, Martin Jucker, Ed Gerber, Ori Adam

- Garfinkel C.I., B. Keller, O. Lachmy, I. P. White, E. P. Gerber, M. Jucker, and O. Adam (submitted). Impact of parameterized convection on the storm track and jet stream response to global warming: implications for mechanisms of the future poleward shift,*Journal of Climate*,.
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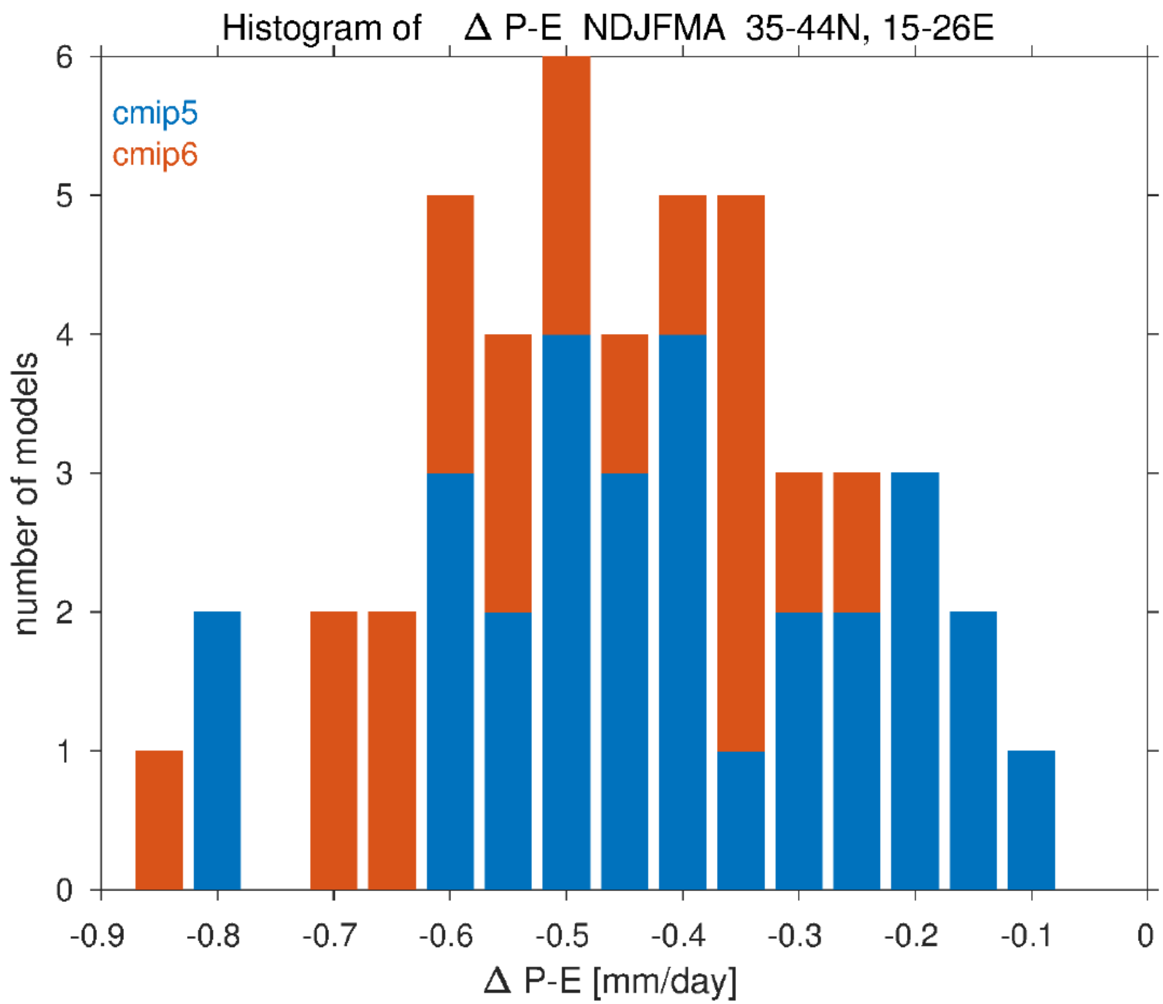
The Challenge: divergent projections of the future

end of century – (2015 to 2034)



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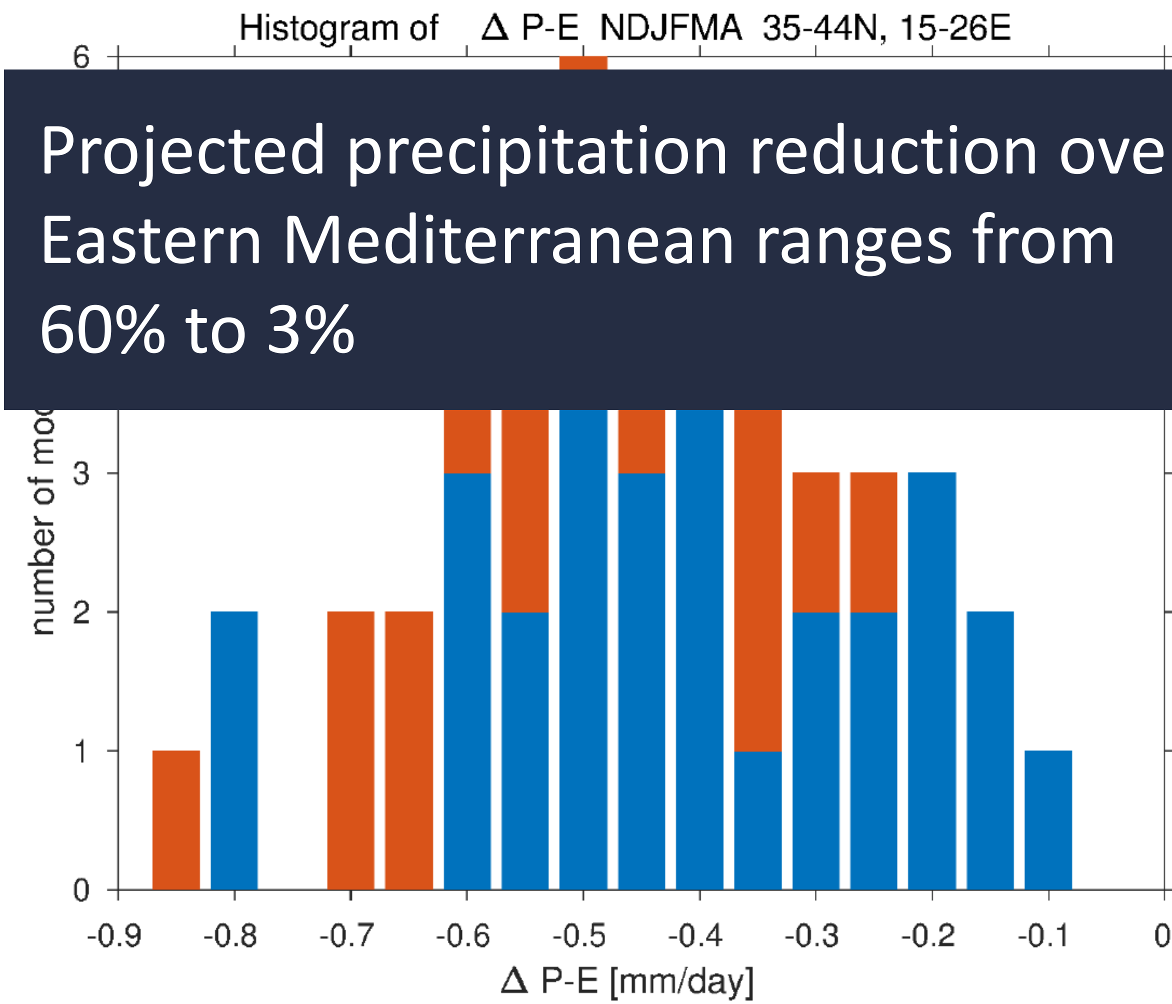

Projected precipitation reduction over Eastern Mediterranean ranges from 60% to 3%

The Challenge: divergent projections of the future

end of century – (2015 to 2034)

Projected precipitation reduction over Eastern Mediterranean ranges from 60% to 3%

This uncertainty is driven ***entirely*** by uncertainty in the changes in circulation (Elbaum et al 2022). Circulation uncertainty drives intermodel spread in precipitation changes essentially everywhere

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The Challenge: divergent projections of the future

end of century – (2015 to 2034)

Projected precipitation reduction over Eastern Mediterranean ranges from 60% to 3%

This uncertainty is driven ***entirely*** by
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pr
everywhere

How does the convection scheme (which is poorly constrained and still changing in CMIP models) affect the dynamic response?

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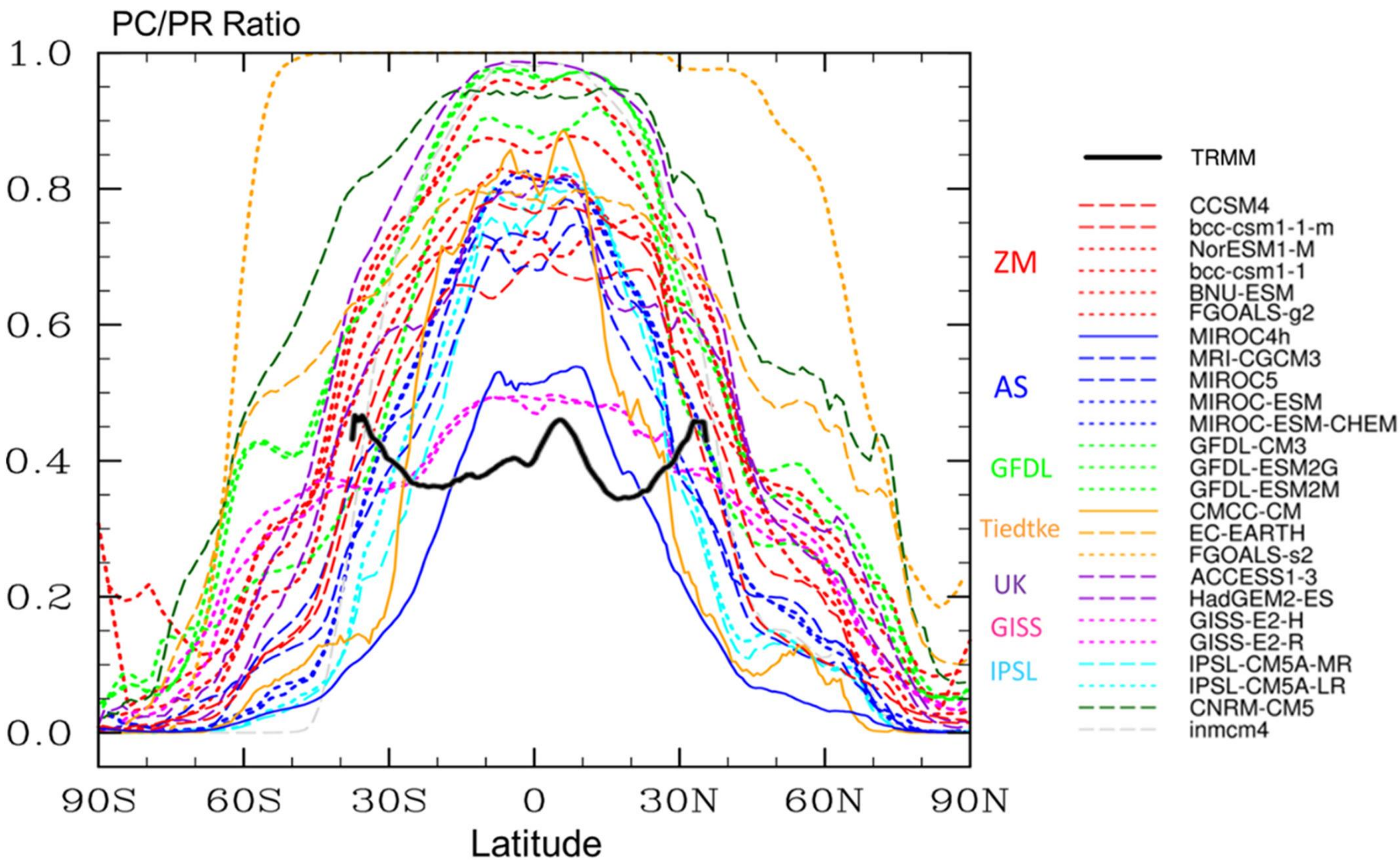
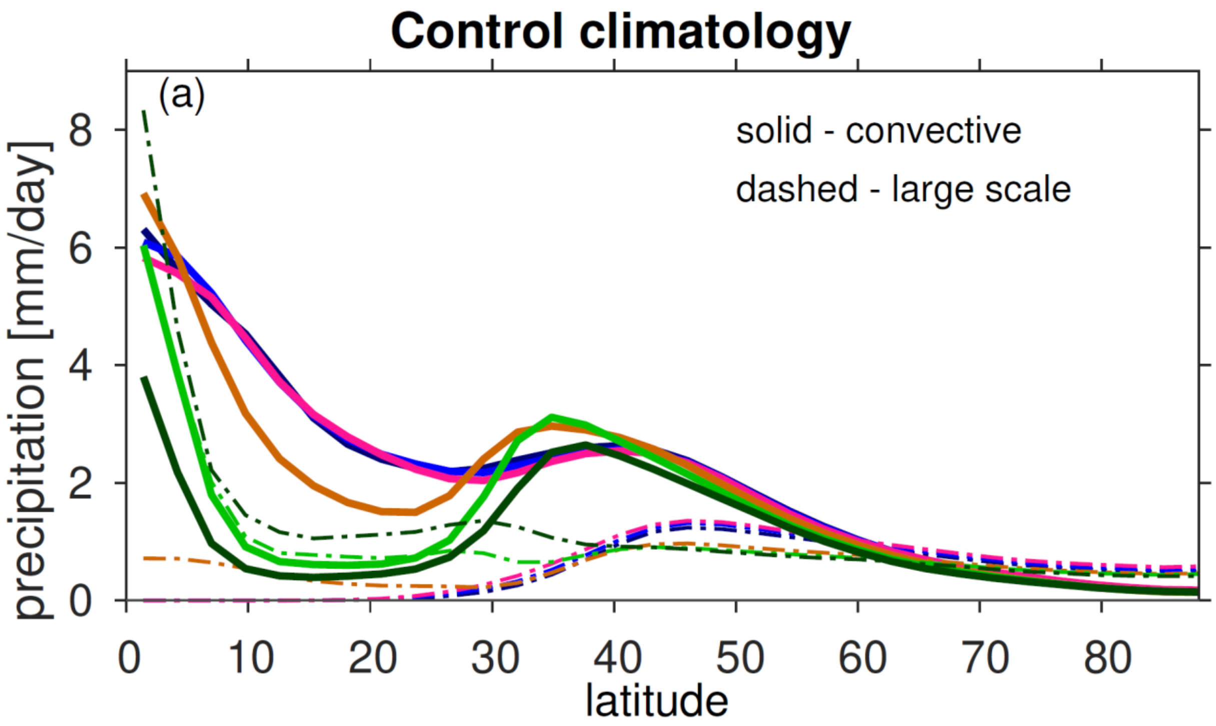
Intermodel spread in role of convection vs large-scale for precip in present-day climate



Chen et al 2021

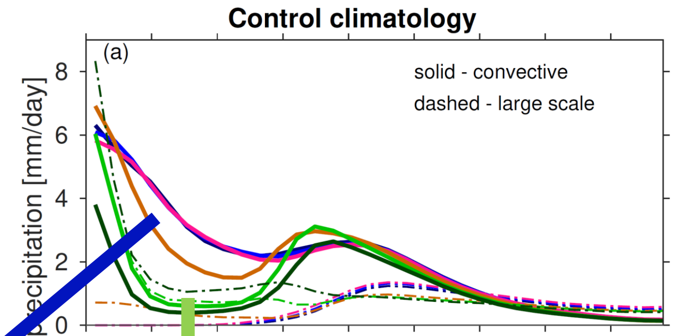
Convection scheme has several poorly constrained parameters

- Whether to use a shallow convection scheme
- Relative humidity for the profile relaxed back towards.



- Pairs of integrations: (1) 390ppmv CO_2; (2) +8K warming (~4xCO_2)

Convection scheme has se constrained param



- Whether to use a shallow convection scheme
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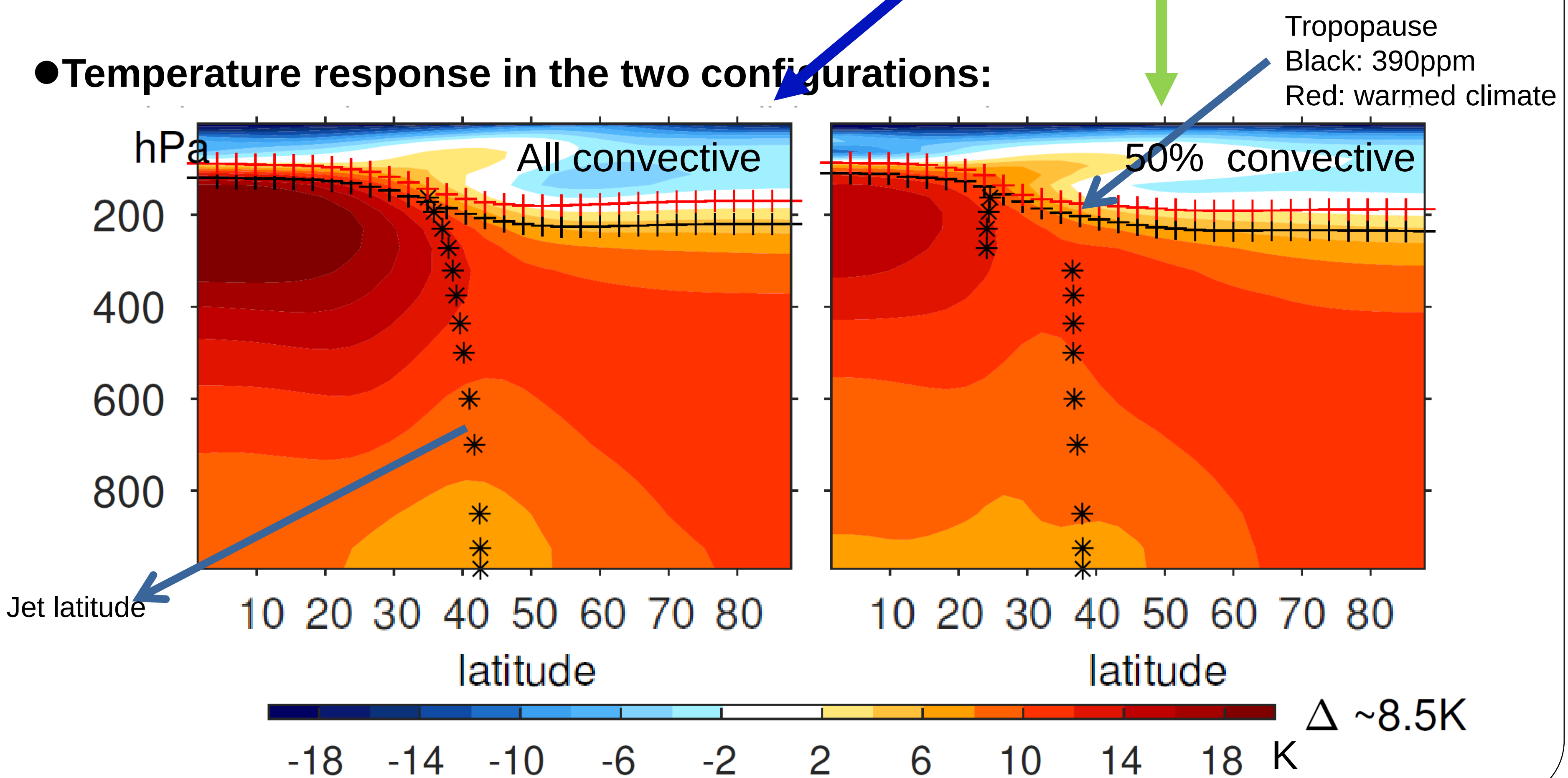
- **Temperature response in the two configurations:**



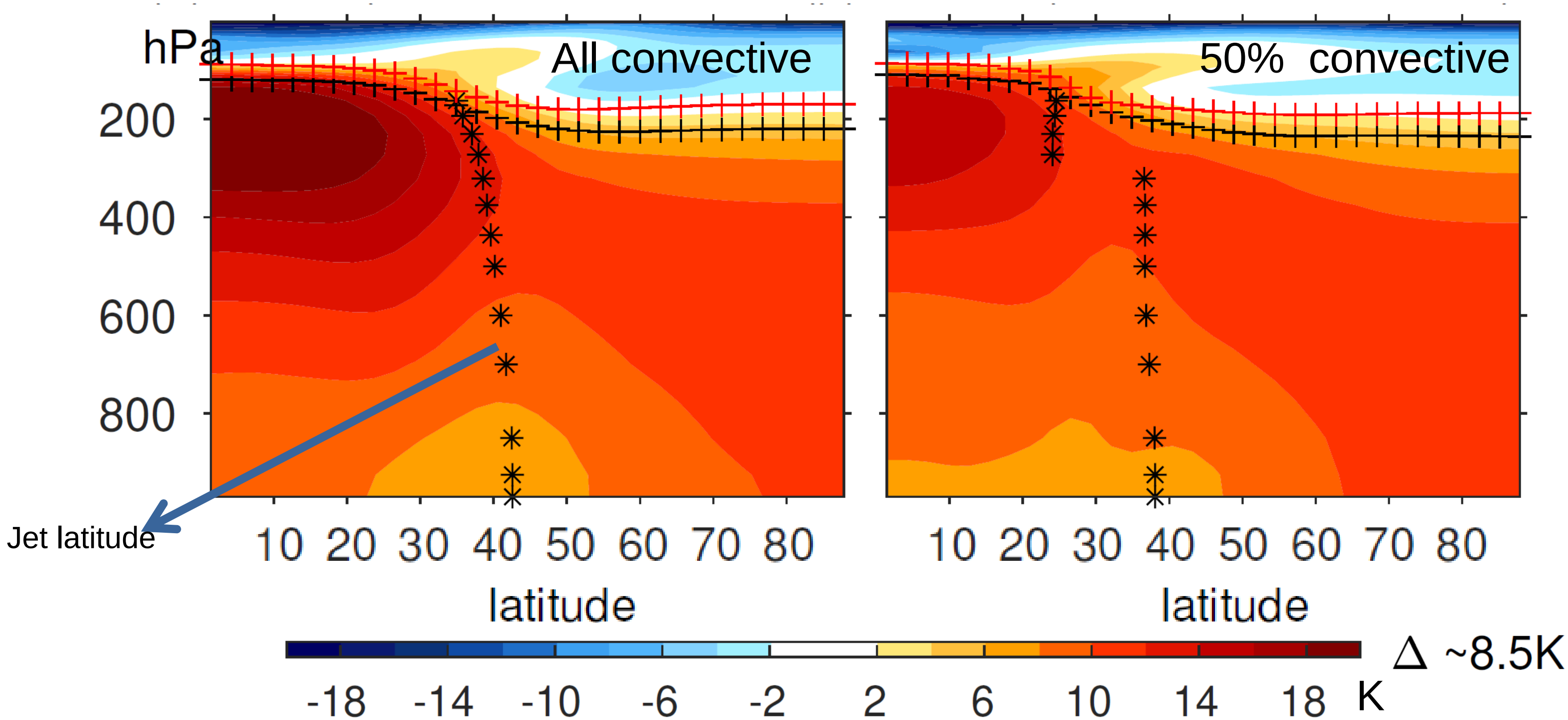
Convecti… c…

Which one has a stronger poleward jet and storm track shift?

Left: two hands in air
Right: one hand in air

- Whether to use a shallo…
- Relative humidity for th…
- Pairs of integrations do… +8K warming (~4xCO2)

- **Temperature response in the two configurations.**



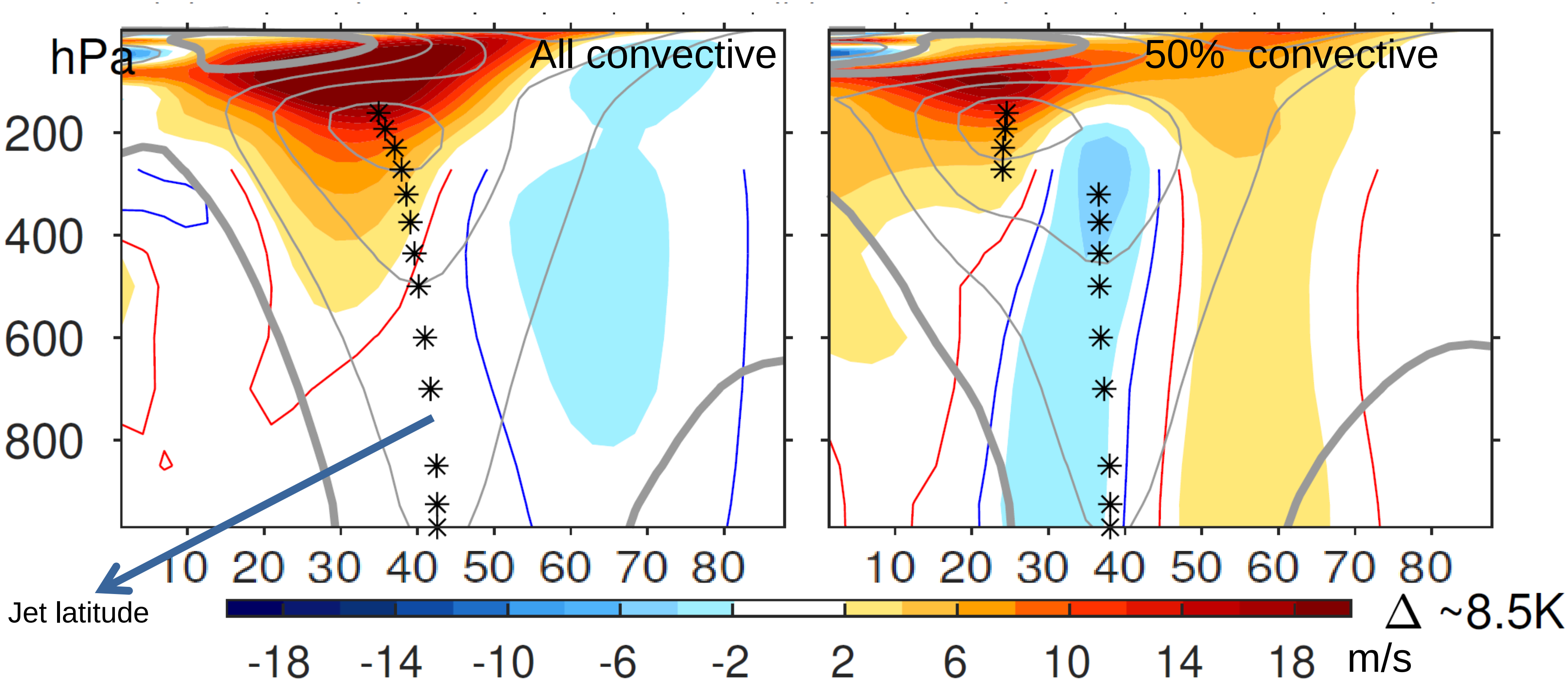
Convecti… c…

Which one has a stronger poleward jet and storm track shift?

Left: jet shifts *equatorwards*

- Whether to use a shallo…
- Relative humidity for th…
- Pairs of integrations: (1…

- **Zonally averaged zonal wind response in the two configurations.**



Possible Explanations for Magnitude of Jet Shift

~~•Tropical upper tropospheric warming~~
~~•Arctic amplification~~
~~•Polar lower stratosphere cooling~~
~~•Rise of the tropopause~~
~~•Increase of subtropical upper tropospheric static stability~~
–
~~•Eddy feedback strength of the eddy driven jet~~
~~•Eddy heat flux~~
~~•Eddy length scale~~
~~•Eddy phase speed~~

•Eddy Momentum Flux
•Diabatic heating poleward of jet core

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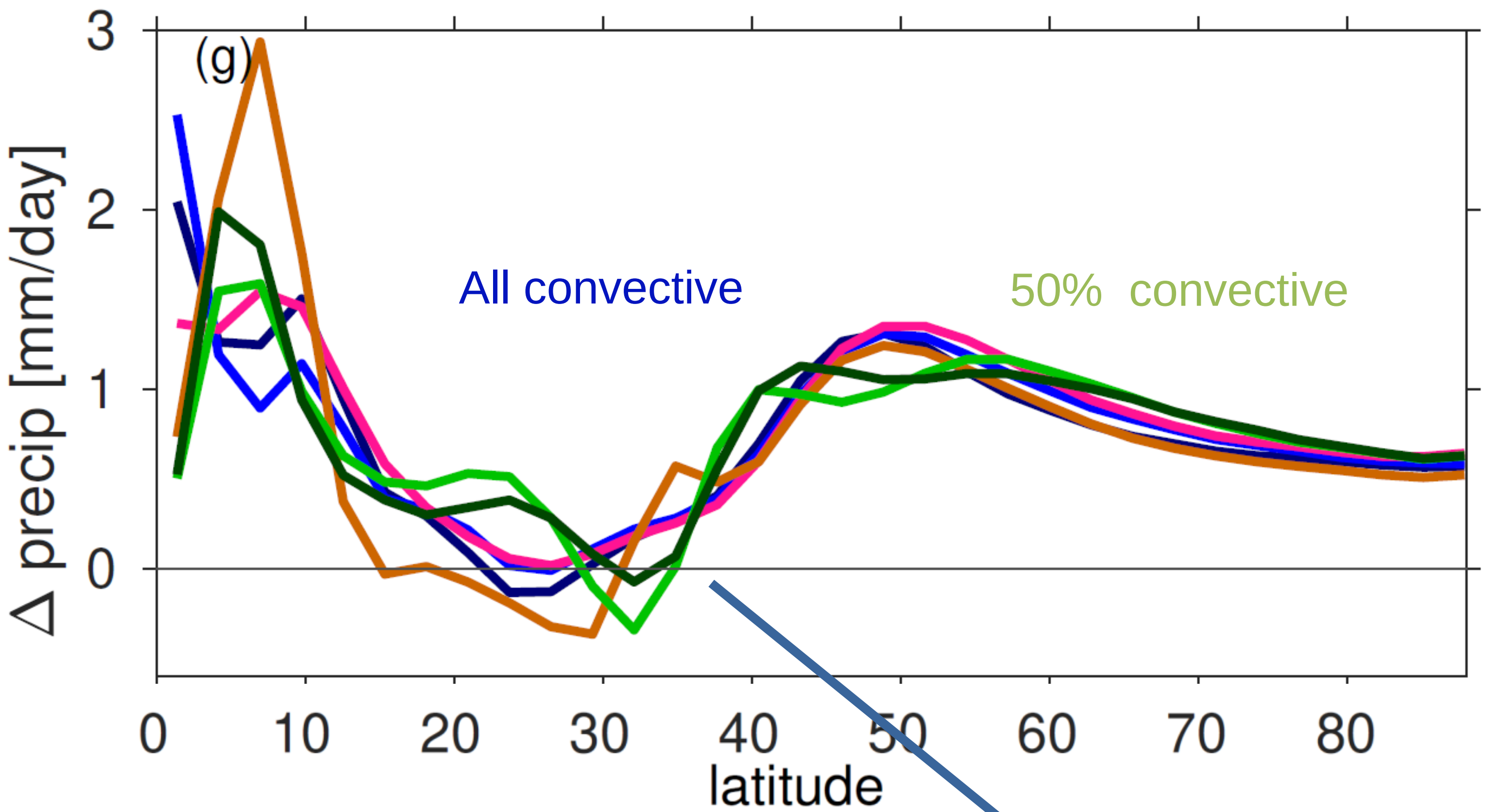
Implications for hydroclimate in the subtropics



Stronger drying near 30deg for
50% convective
configuration with strong jet shift

Conclusions:

At least four distinct processes may explain intermodel spread in the tropospheric response to ozone depletion. We are only beginning to quantify their relative importance. **Interested in exploring this, and subsequent impacts on SH surface climate and extremes, as part of EPESC.**

The parameterized subgrid-scale convection has a **leading-order effect** on the projected poleward shift of storm tracks and the jets (Garfinkel et al, submitted), perhaps a

Many of th are
not capab l,
submitted)

Take home message: Attribution statements and future projections linking some extreme to human activity will lack full confidence if different models cannot agree on how human activity is changing the atmospheric circulation.

I would be interested in joining any EU Horizon Europe consortium related to EPESC (Israel is an associated country)

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Australian Bushfires 2019/2020

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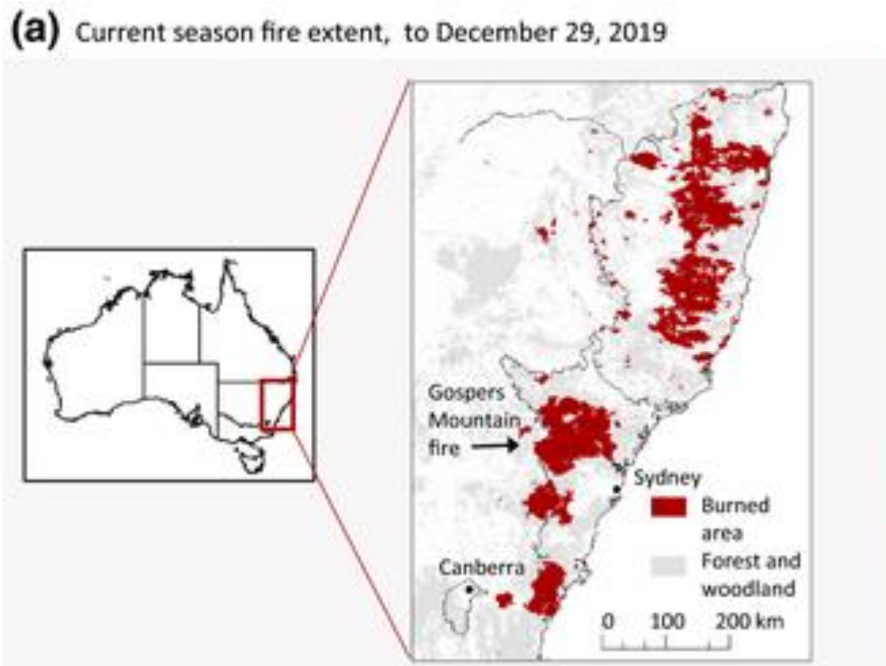
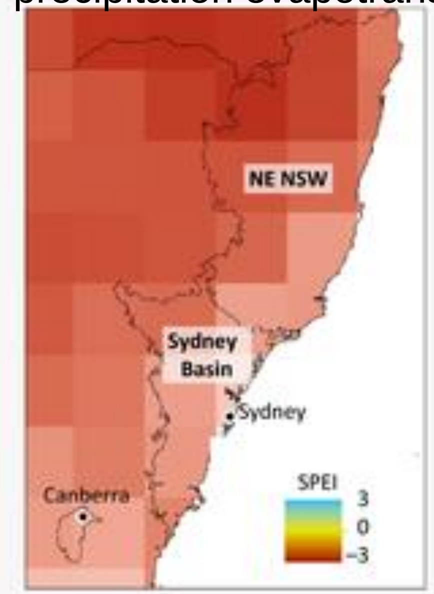
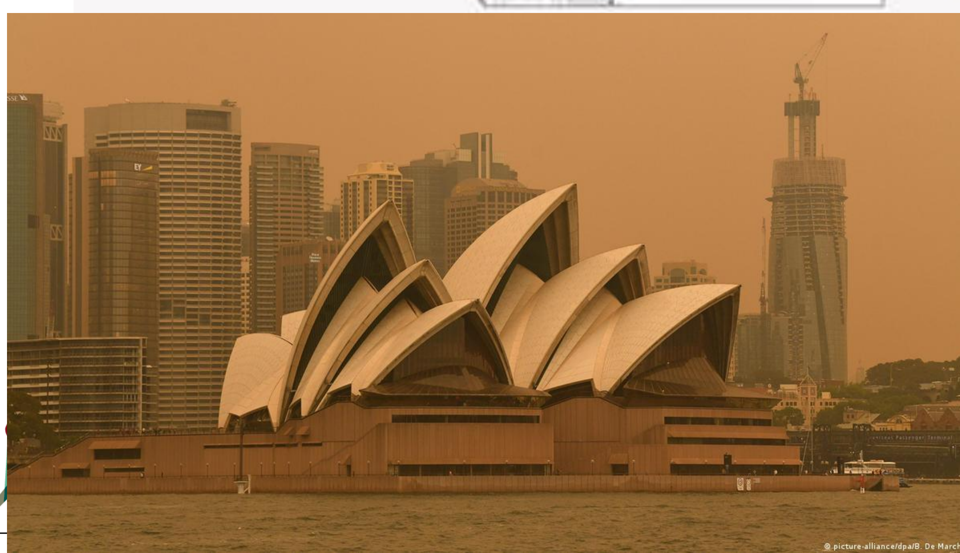
Australian Bushfires 2019/2020





precipitation evapotranspiration



Nolan et al. 2020

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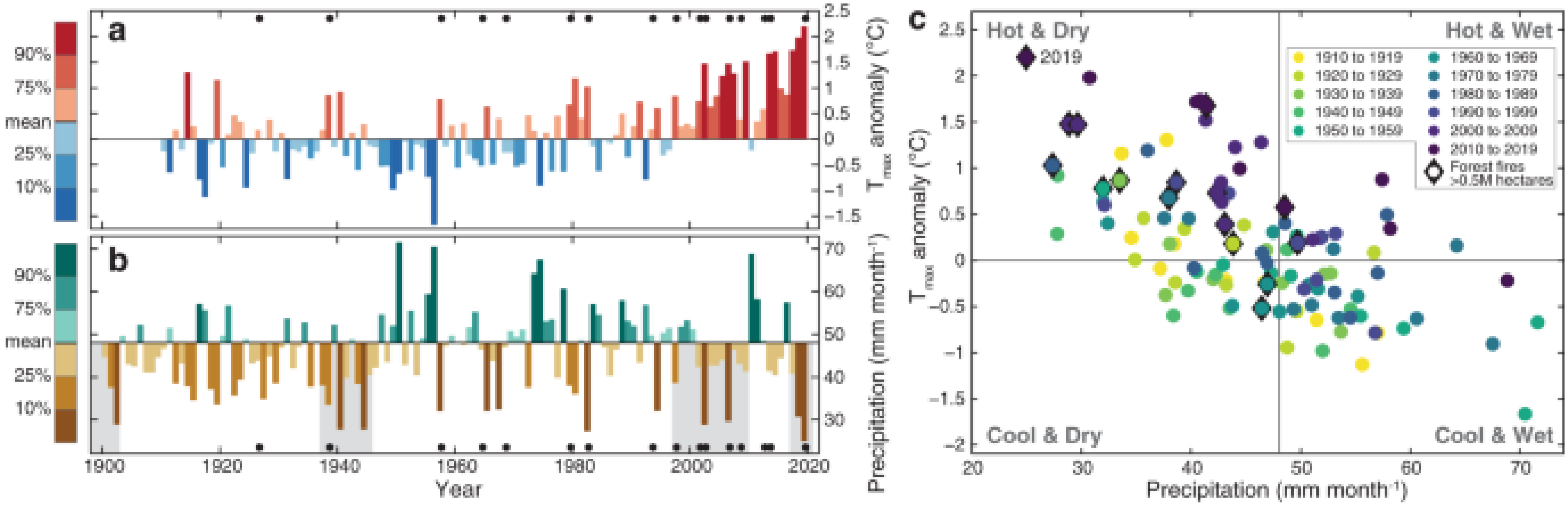
Australian Bushfires 2019/2020



Adam et al. 2021

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Chaim I. Garfinkel

Key Questions:

Can we predict/project/attribute such an event?

- how far in advance is such a dry and hot combination predictable, and are models actualizing the potential predictability?
- what is the role of sea surface temperatures vs. the stratosphere?
- are model biases leading to a misrepresentation of the underlying processes?

Key Questions:

- how far in advance is such a dry and hot combination predictable, and are models actualizing the potential predictability?
- **what is the role of** sea surface temperatures vs. **the stratosphere**?
- are model biases leading to a misrepresentation of the underlying processes?

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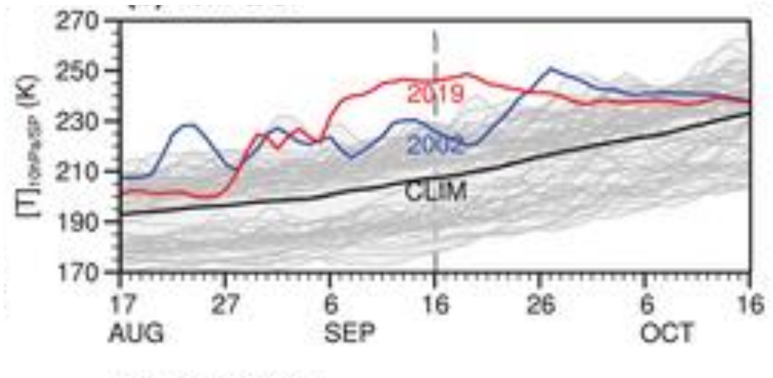
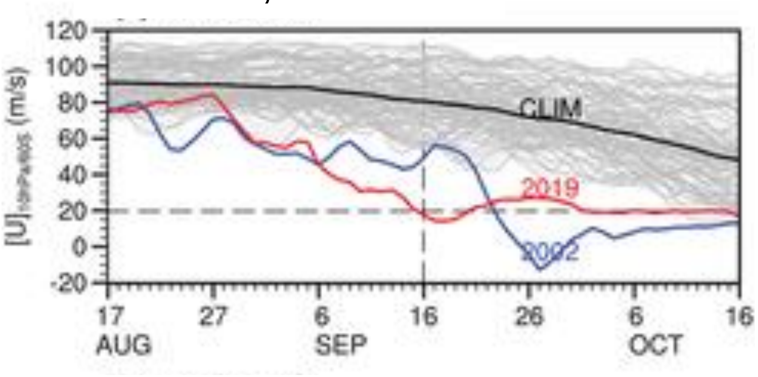
September 2019 SH sudden warming

T 10hPa, 65S-pole

Rao et al 2020



U 10hPa, 60S



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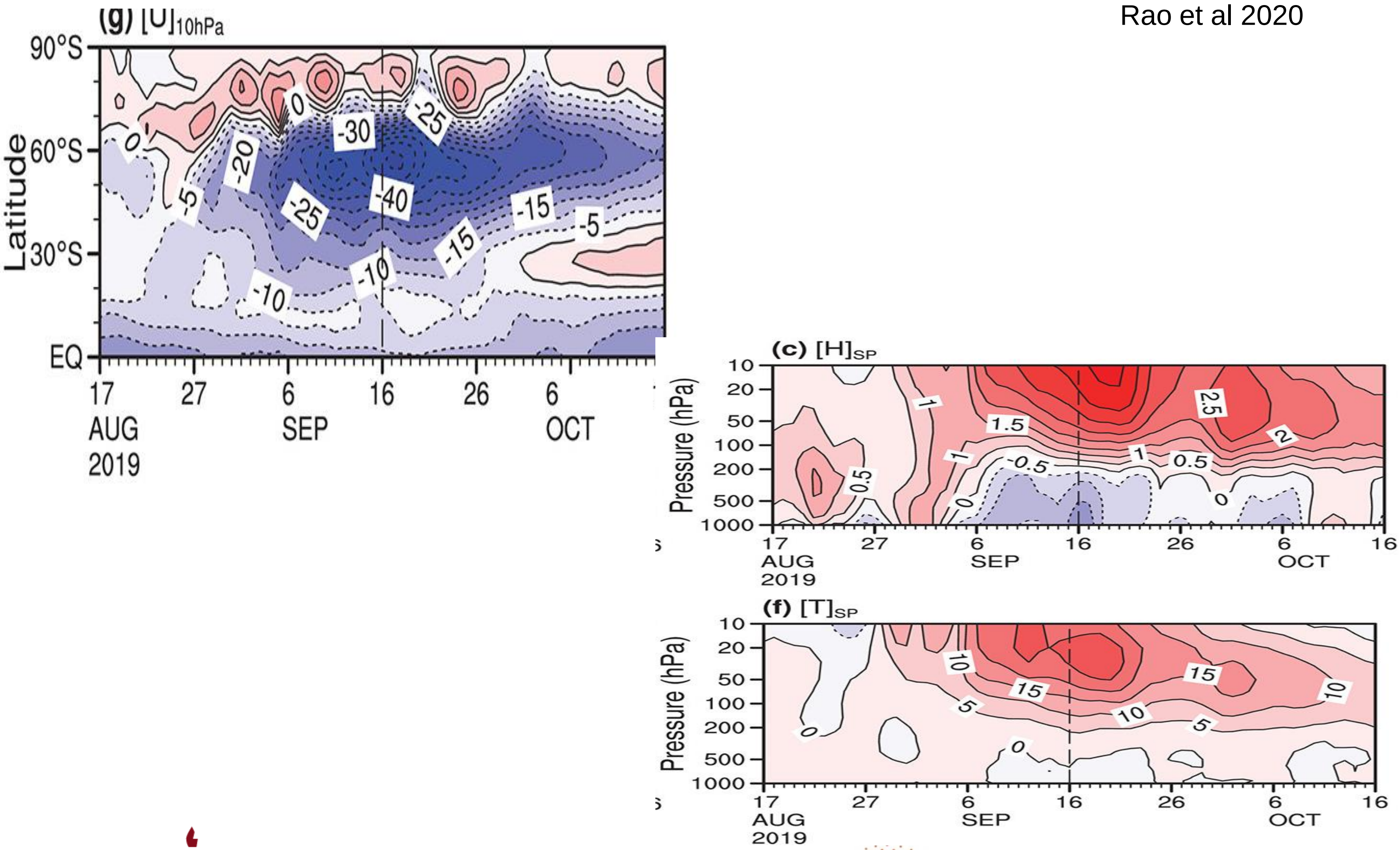
Downward Propagation of Signal in October

Rao et al 2020



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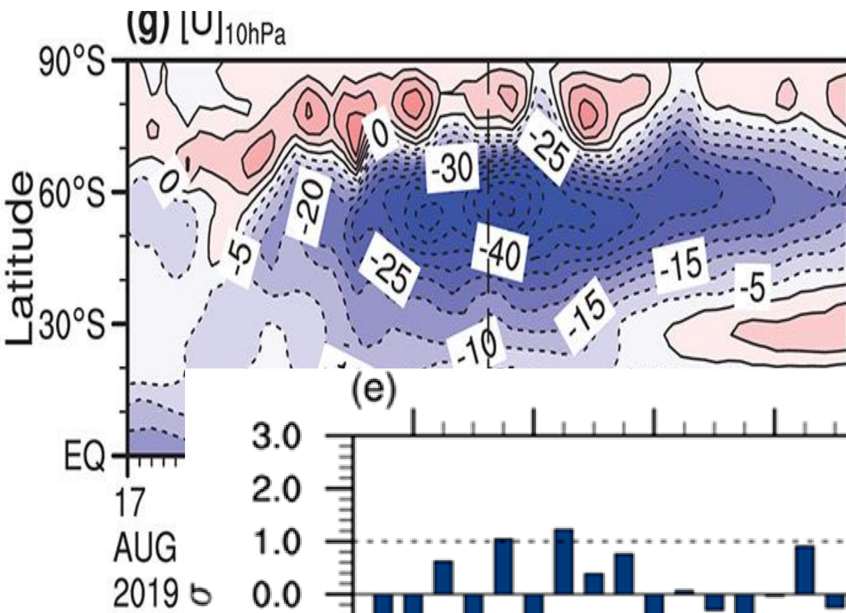
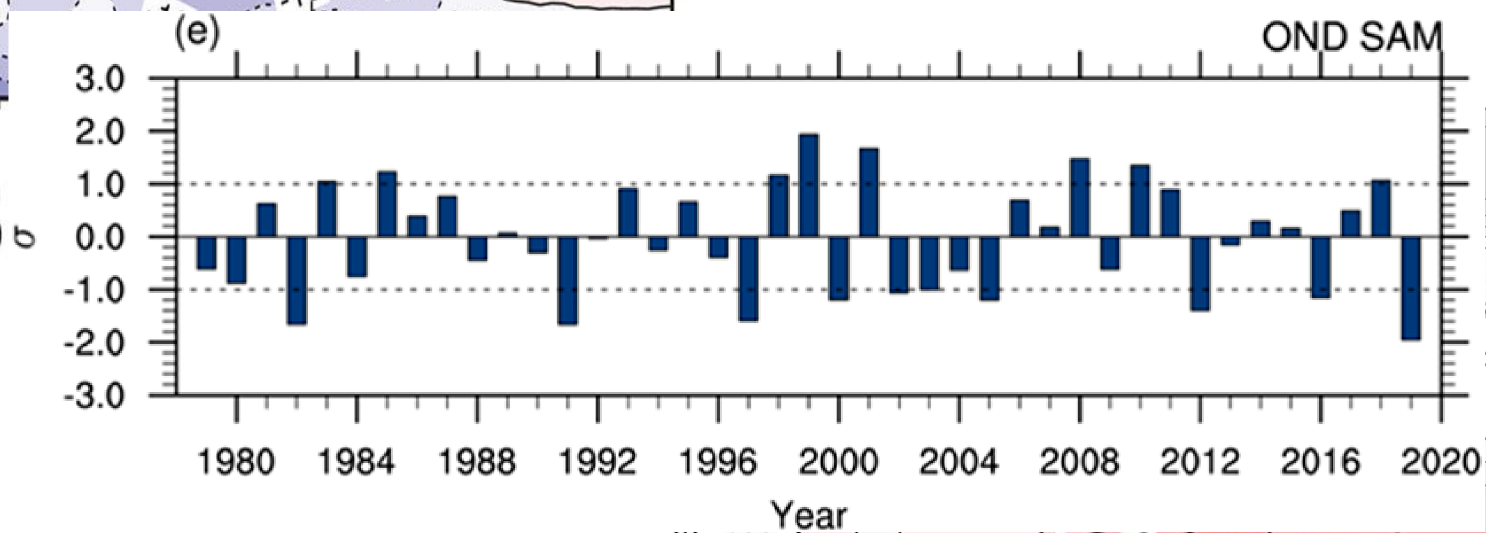
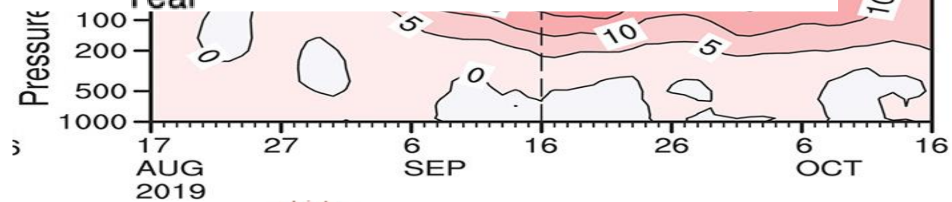
Downward Propagation of Signal in October

Rao et al 2020



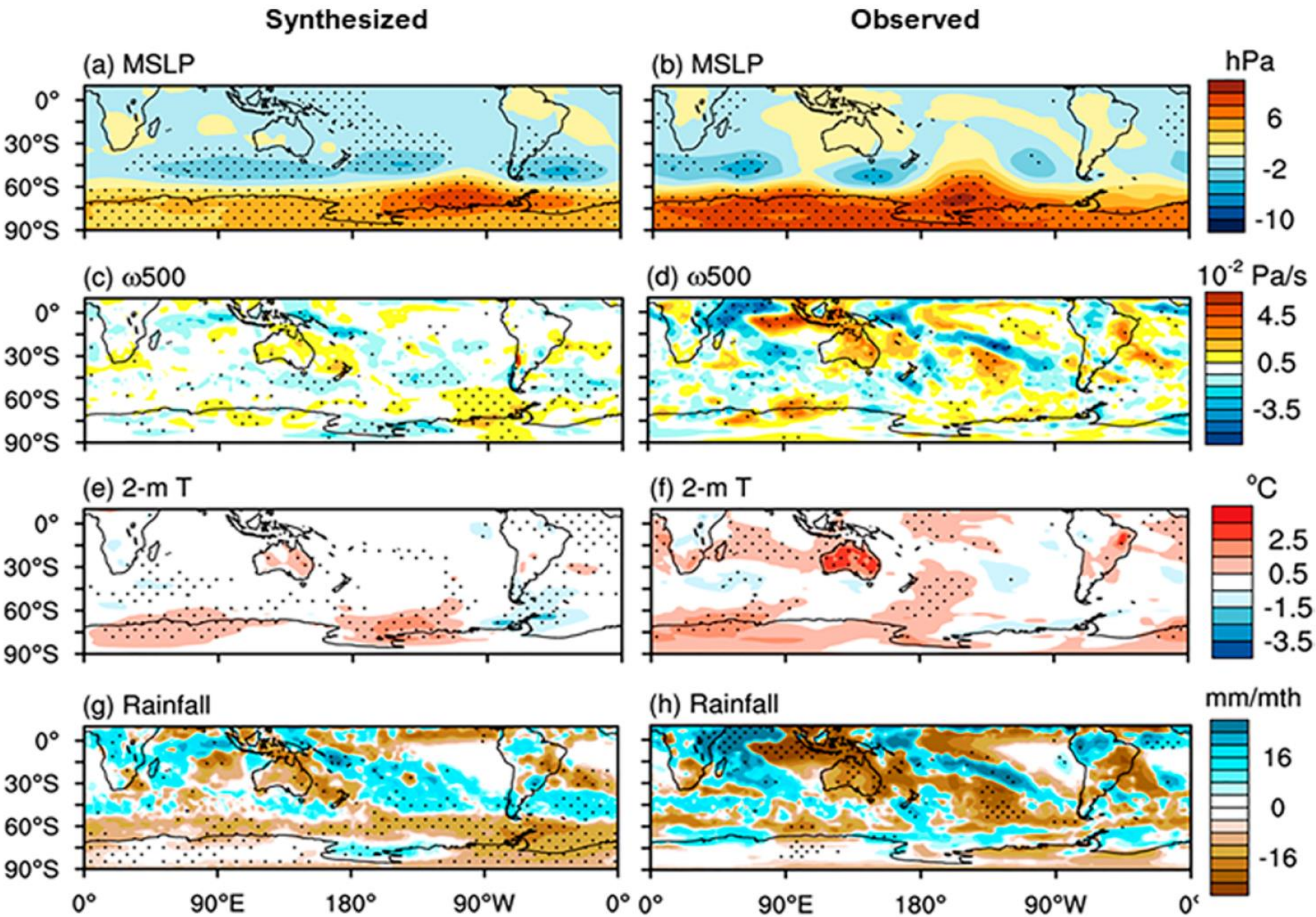




Lim et al 2021

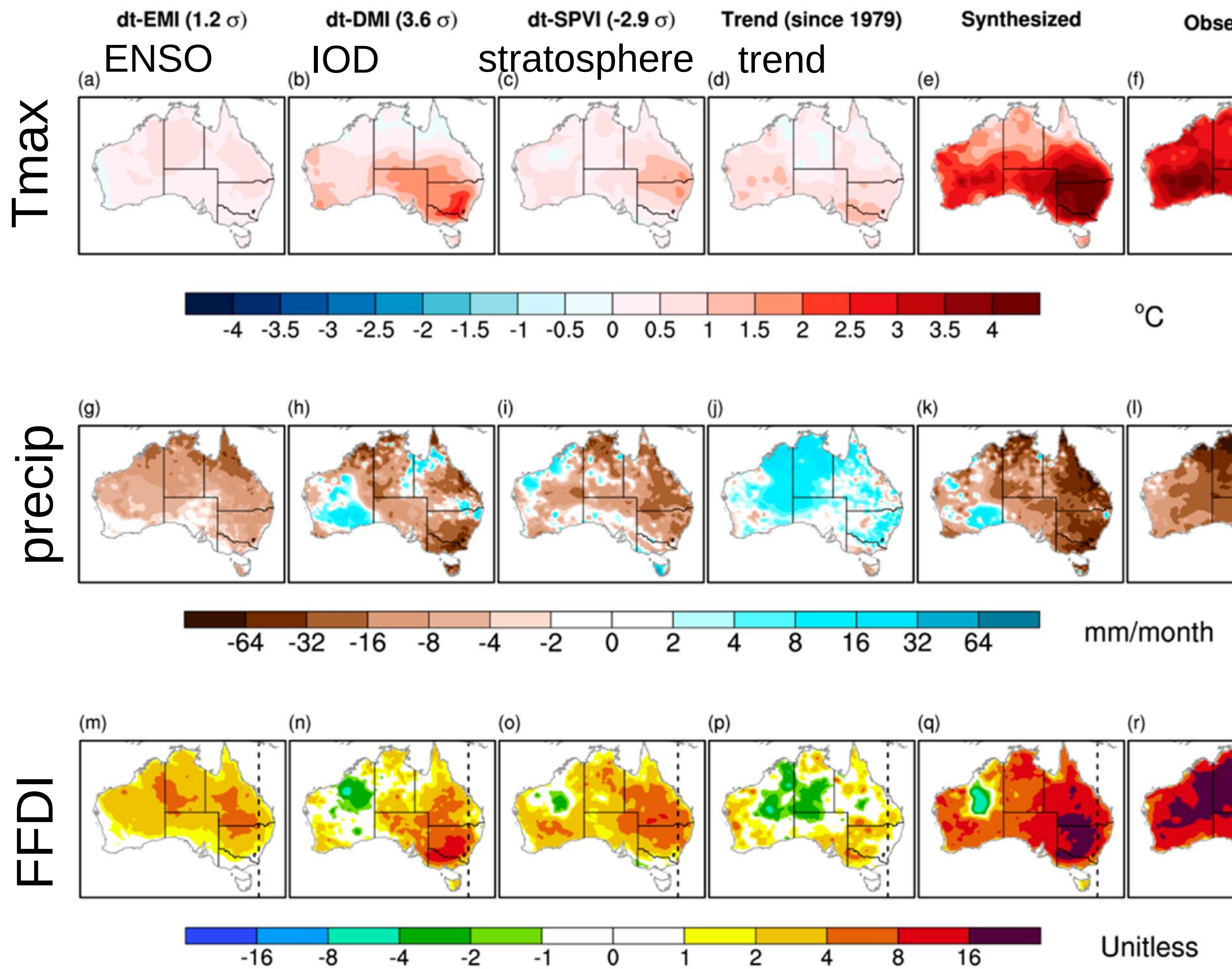
Chaim I. Garfinkel

Impacts in October through December



Lim et al 2021

Impacts in October through December
Multiple linear regression



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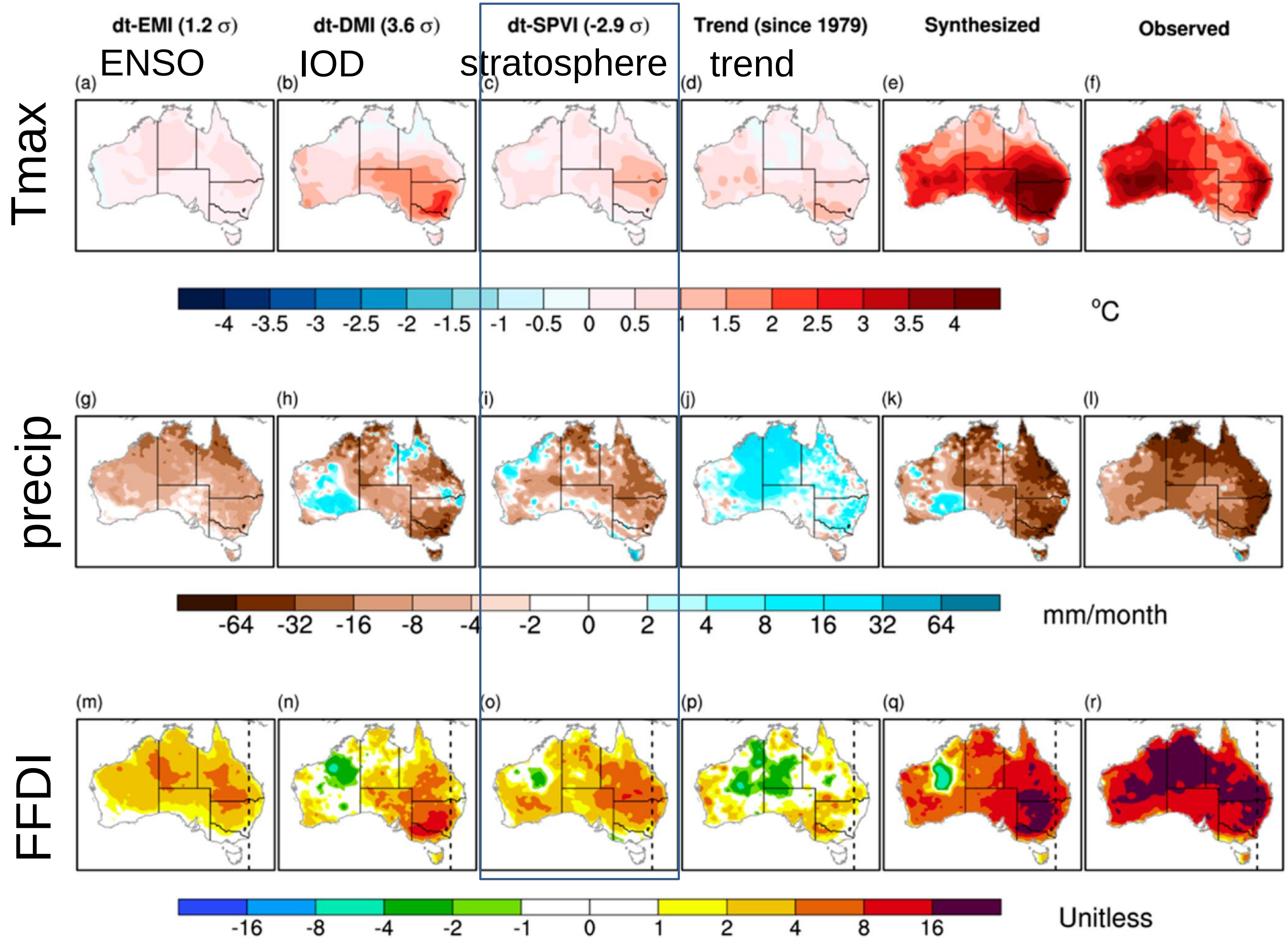
Multiple linear regression



Stratosphere the most important factor for Eastern Australia

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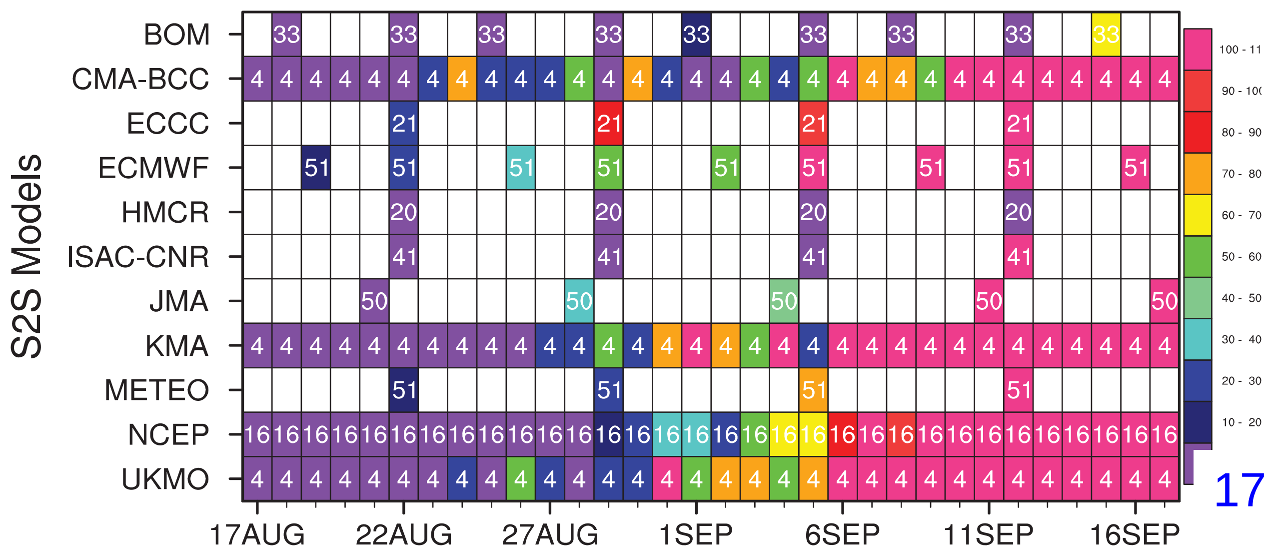
Lim et al 2021

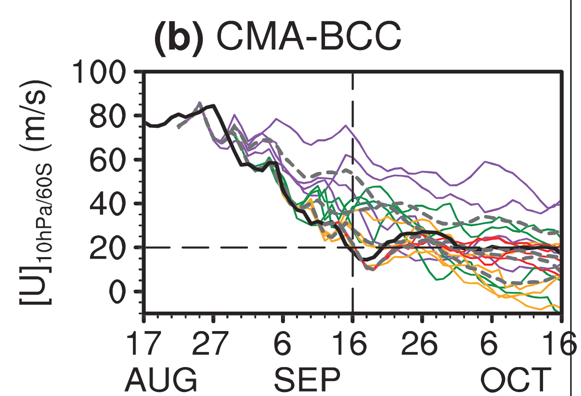
Did subseasonal models capture this?

Rao et al 2020

Prediction success ratio (hit ratio)



17 Sep 2019

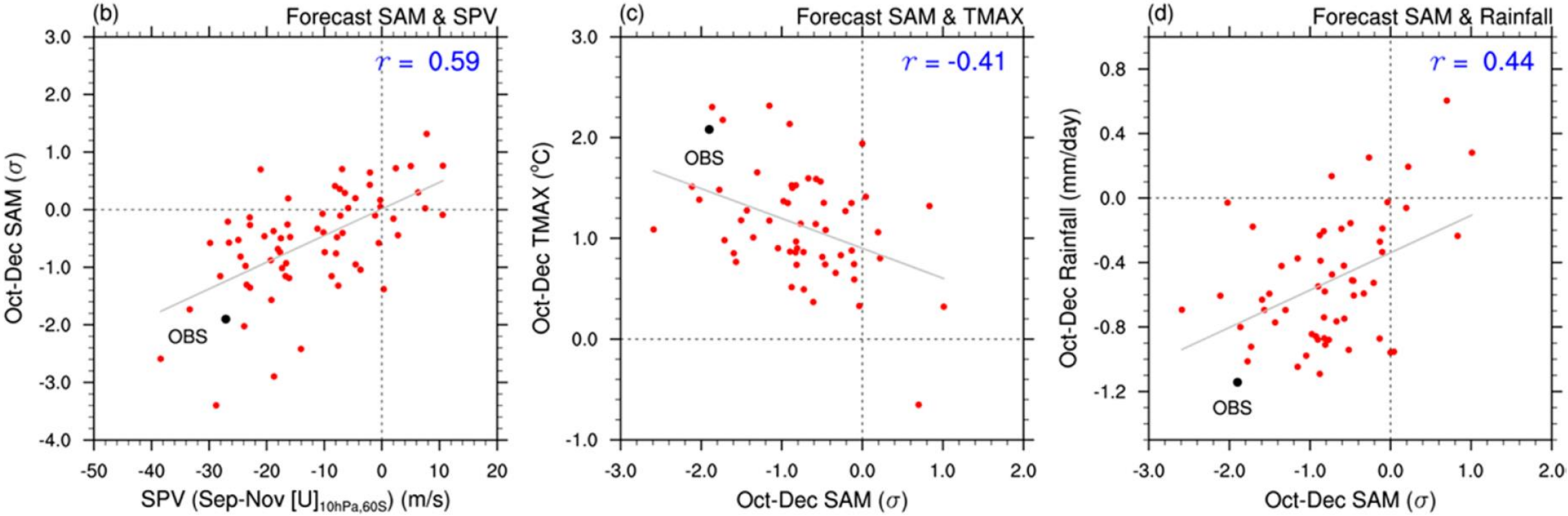


Thresholds: 20m/s for SH SSW

Chaim I. Garfinkel

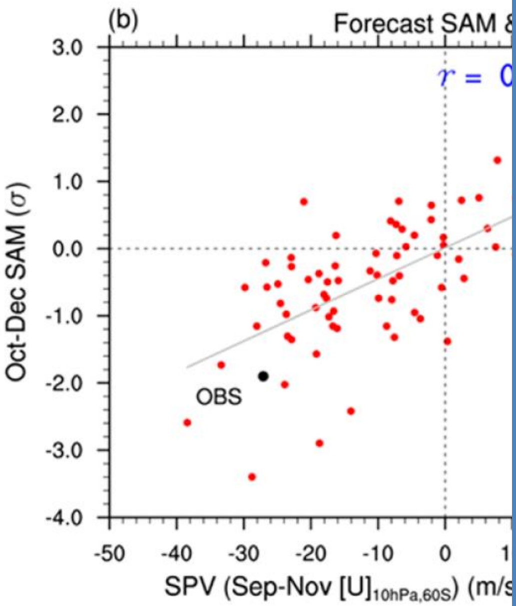
Surface Impacts in seasonal forecasts

Lim et al 2021



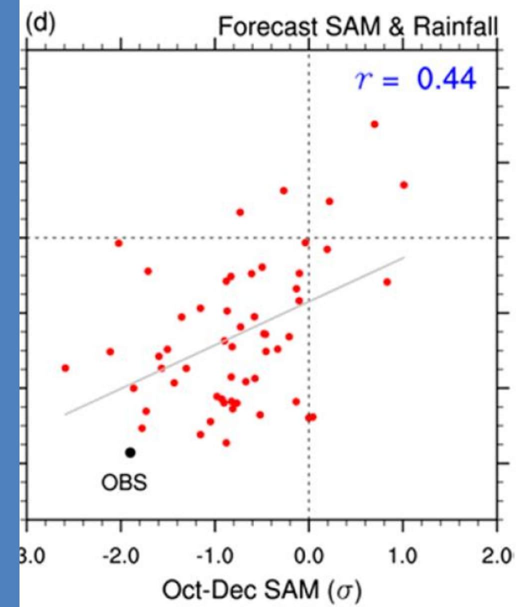
Surface Impacts in seasonal forecasts

Lim et al 2021



Why does this matter for EPESC WG2?

Integrated Attribution, Prediction and Projection of future changes in the Southern Hemisphere needs to take into consideration the stratosphere



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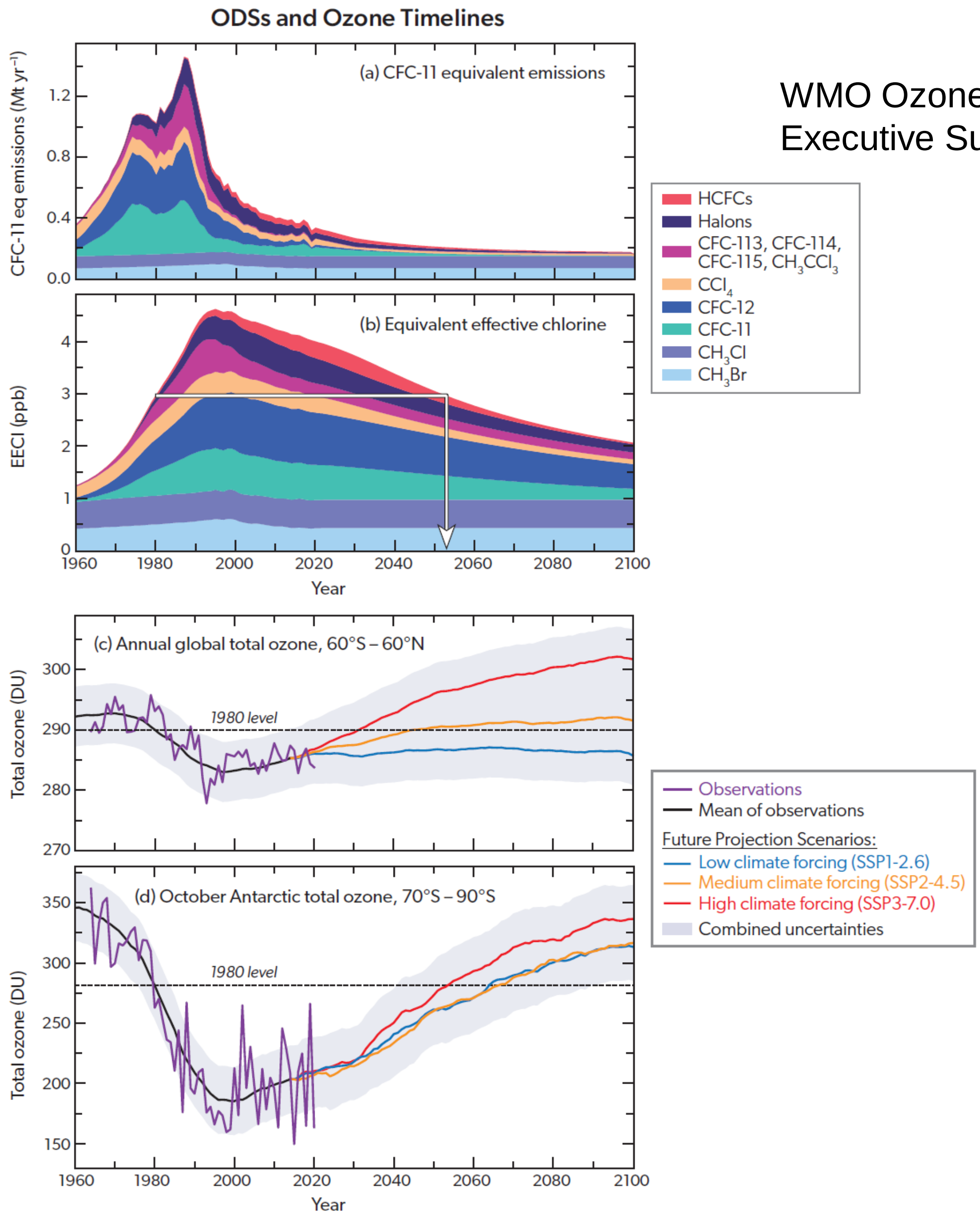
Chaim I. Garfinkel

Outlook:
Ozone recovery has already started

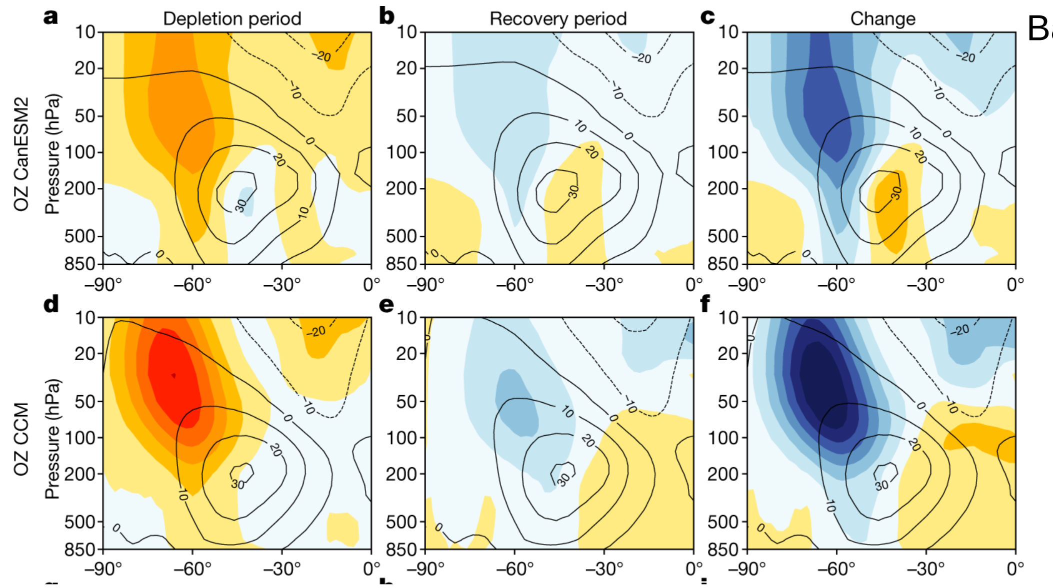


WMO Ozone Assessment 2022
Executive Summary

Outlook:
How will the SH vortex change in the future?

Banerjee et al 2020

Ozone only



Outlook:
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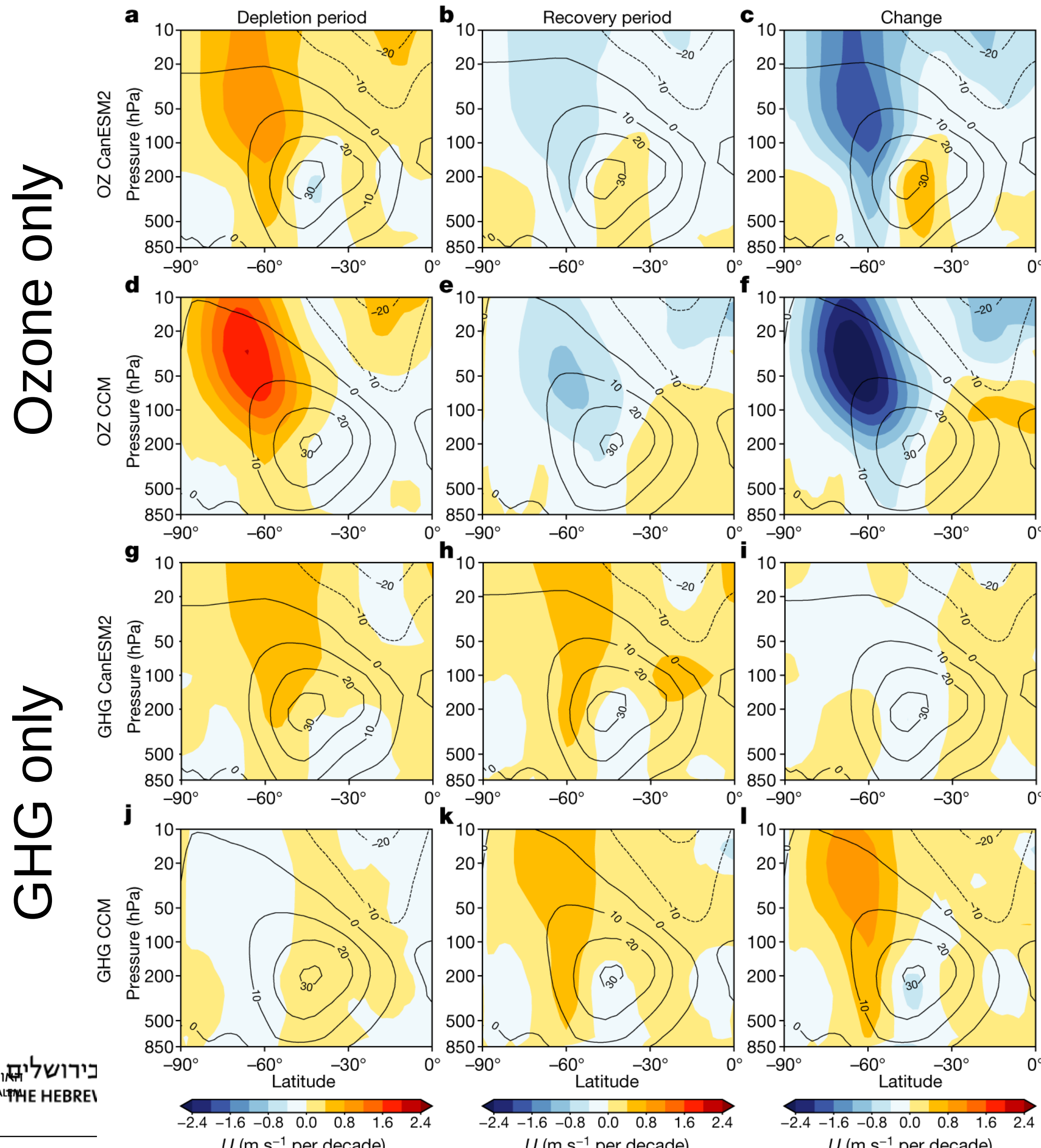

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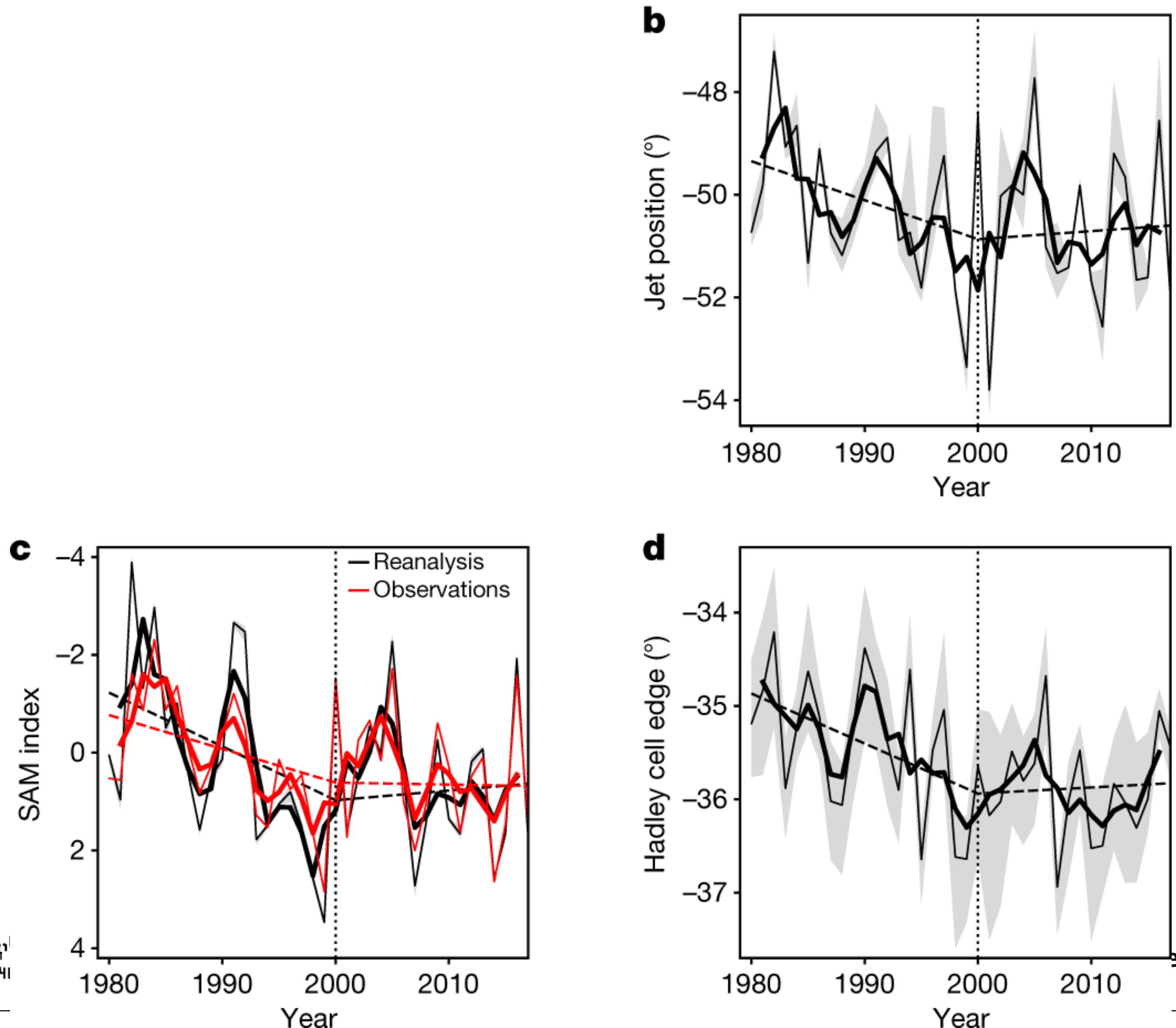
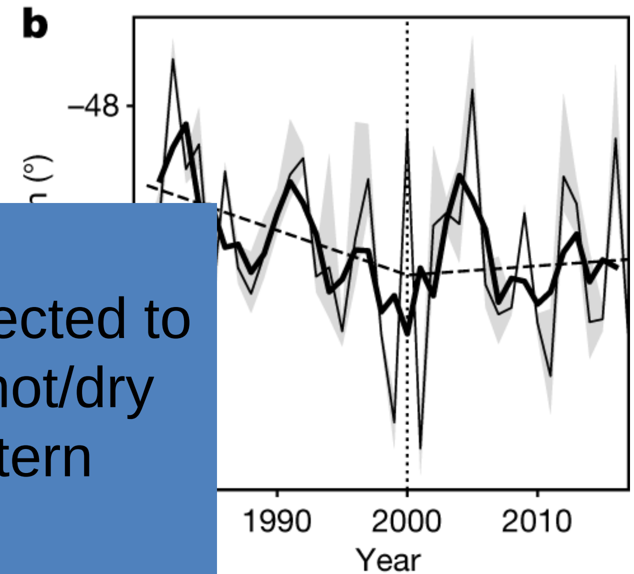
Outlook:
Surface trends are already beginning to reverse

Banarjee et al 2020

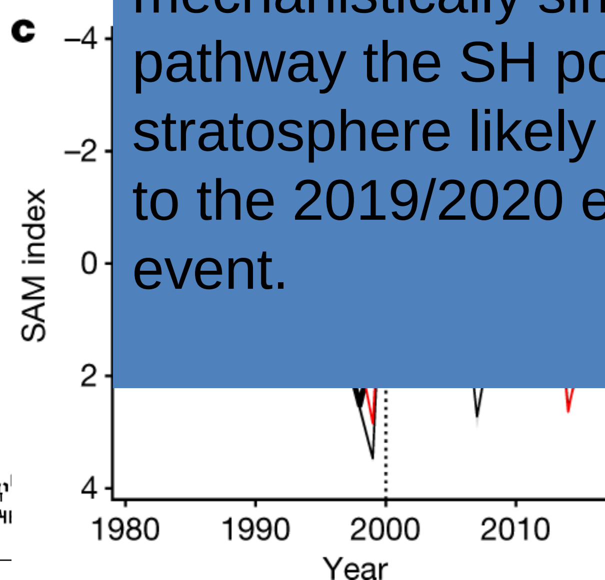


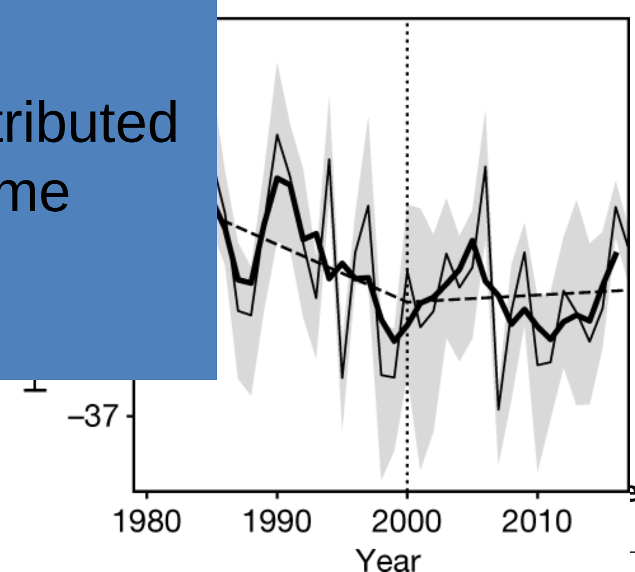
Outlook:
Surface trends are already beginning to reverse

Banarjee et al 2020



Ozone recovery is expected to lead to more frequent hot/dry conditions in Southeastern Australia, and via a mechanistically similar pathway the SH polar stratosphere likely contributed to the 2019/2020 extreme event.





Summary:

• how far in advance is such a dry and hot combination predictable, and are models actualizing the potential predictability? **Seasonal but also decadal**

• what is the role of sea surface temperatures vs. the stratosphere? **Both important. Weak SH polar vortices will become more frequent as ozone recovers**

• are model biases leading to a misrepresentation of the underlying processes? **Needs more investigation**

Take Home Message: If we want to attribute/predict/project events such as the Australian Bushfires, we need to pay attention to the stratosphere

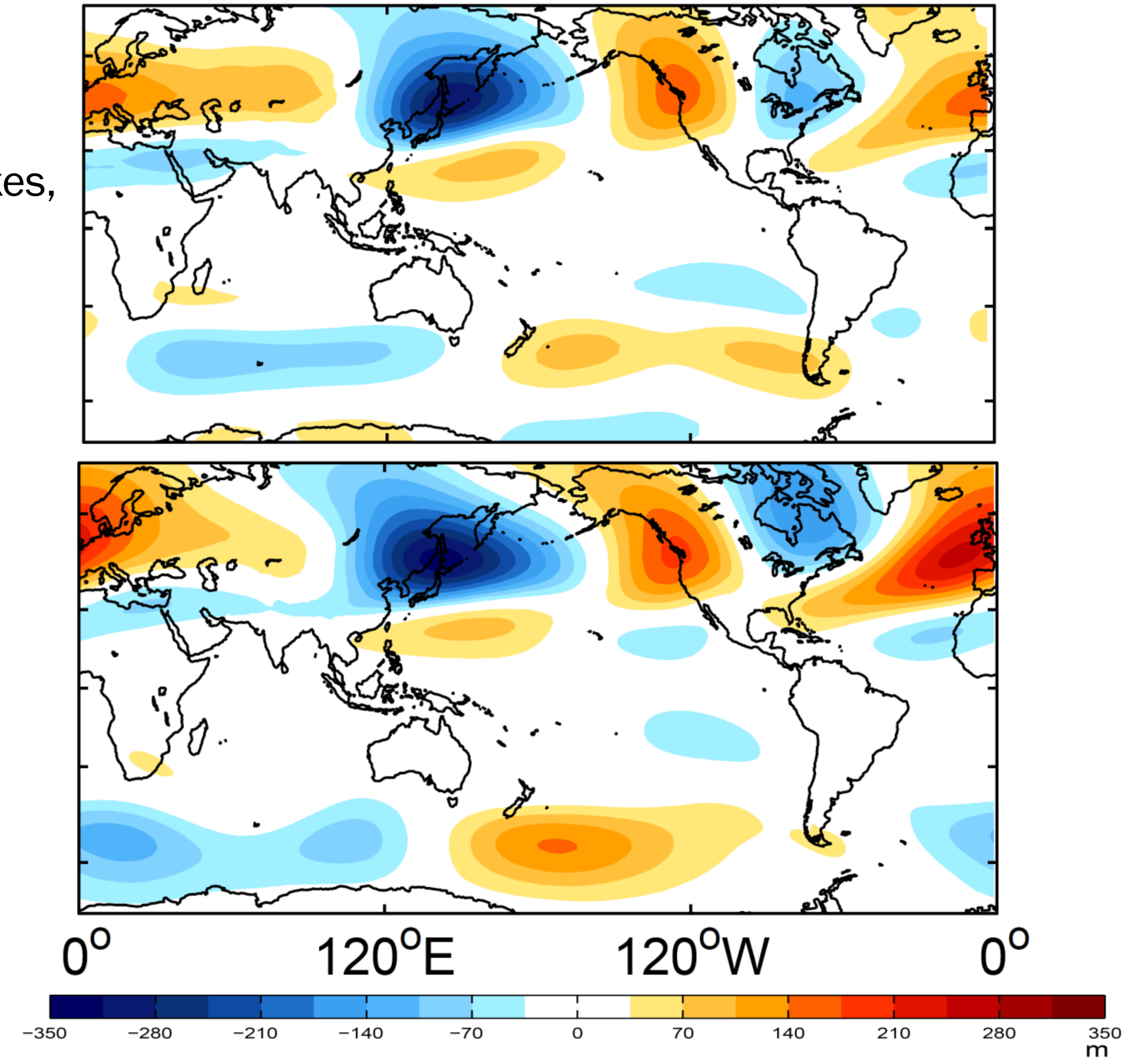
MiMA

- Primitive equations based aquaplanet GCM
- Full radiation scheme (RRTMG). Non-interactive ozone profile.
- Topography, land-sea contrast, east-west ocean heat fluxes

Realism of DJF stationary waves when all forcings included (Z* at 300hPa)

ALL,
(+east-west ocean fluxes,
+land/sea contrast
+topography)

ERA-5 reanalysis



Garfinkel et al, 2020 J Clim.

Eastern Mediterranean Drying: Projected Changes in Dynamics and Thermodynamics and Their Relation to Large-Scale Processes

Eilat Elbaum, **Chaim Garfinkel**, Efrat Morin, Ori Adam, Yehoudah Enzel, Maya Bartov, Dorita Rostkier-Edelstein, Uri Dayan

Garfinkel, C. I., Adam, O., Morin, E., Enzel, Y., Elbaum, E., Bartov, M., Rostkier-Edelstein, D., & Dayan, U. (2020). The Role of Zonally Averaged Climate Change in Contributing to Intermodel Spread in CMIP5 Predicted Local Precipitation Changes, *Journal of Climate*, *33*(3), 1141-1154.

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משרד המדע והטכנולוגיה

What processes lead to uncertainty in projected changes in the hydrologic cycle?

Eilat Elbaum, **Chaim Garfinkel**, Efrat Morin, Ori Adam, Yehoudah Enzel, Maya Bartov, Dorita Rostkier-Edelstein, Uri Dayan

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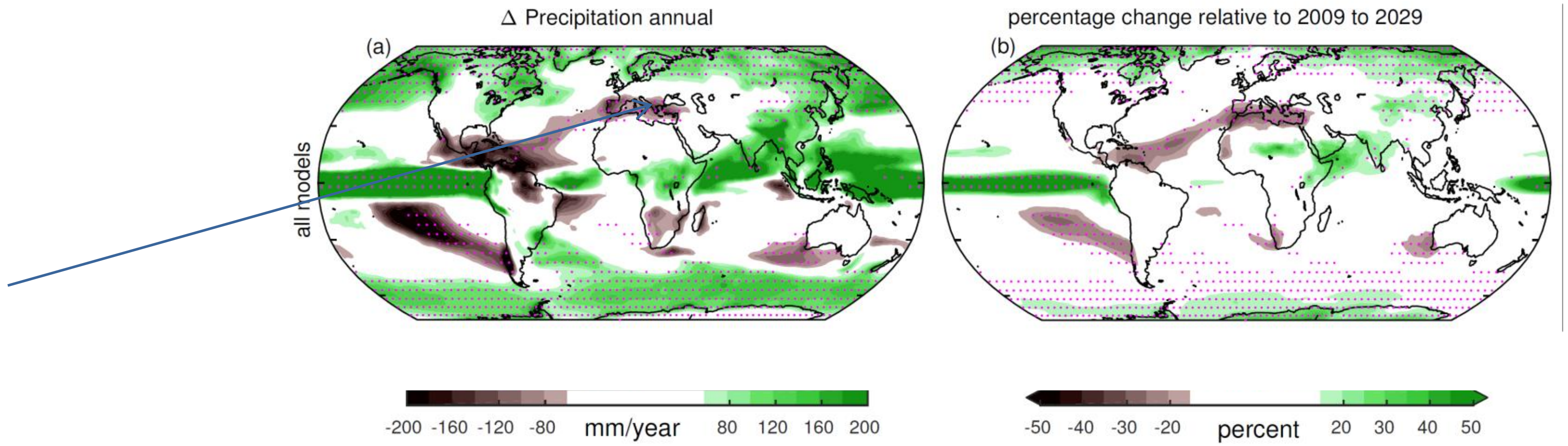
משרד המדע
והטכנולוגיה

The Challenge: the future

CMIP5, RCP8.5 end of century – (2009 to 2029), annual average

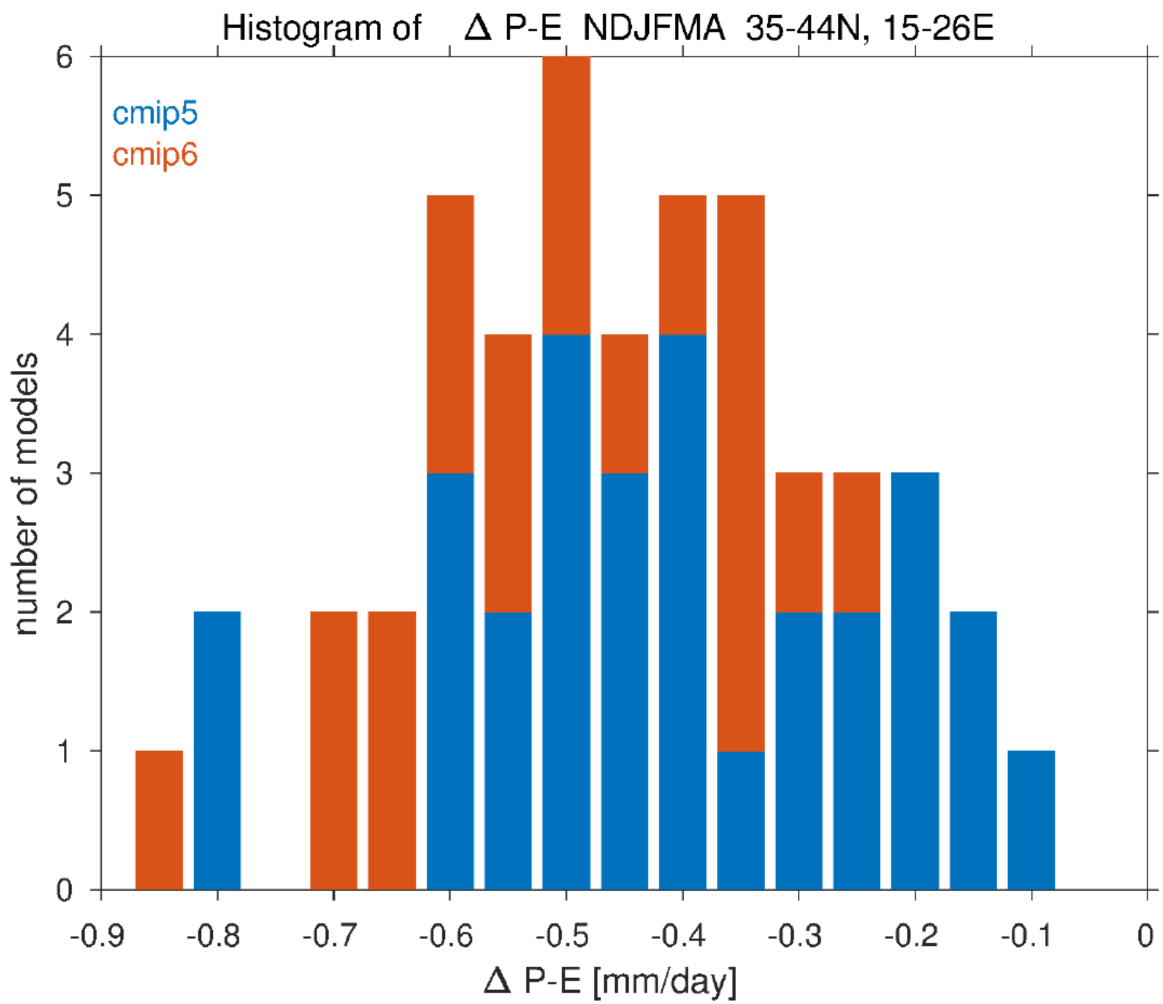


Garfinkel et al 2020

~15-25% decline in Eastern Mediterranean

The Challenge: divergent projections of the future

end of century – (2015 to 2034)



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The Challenge: divergent projections of the future

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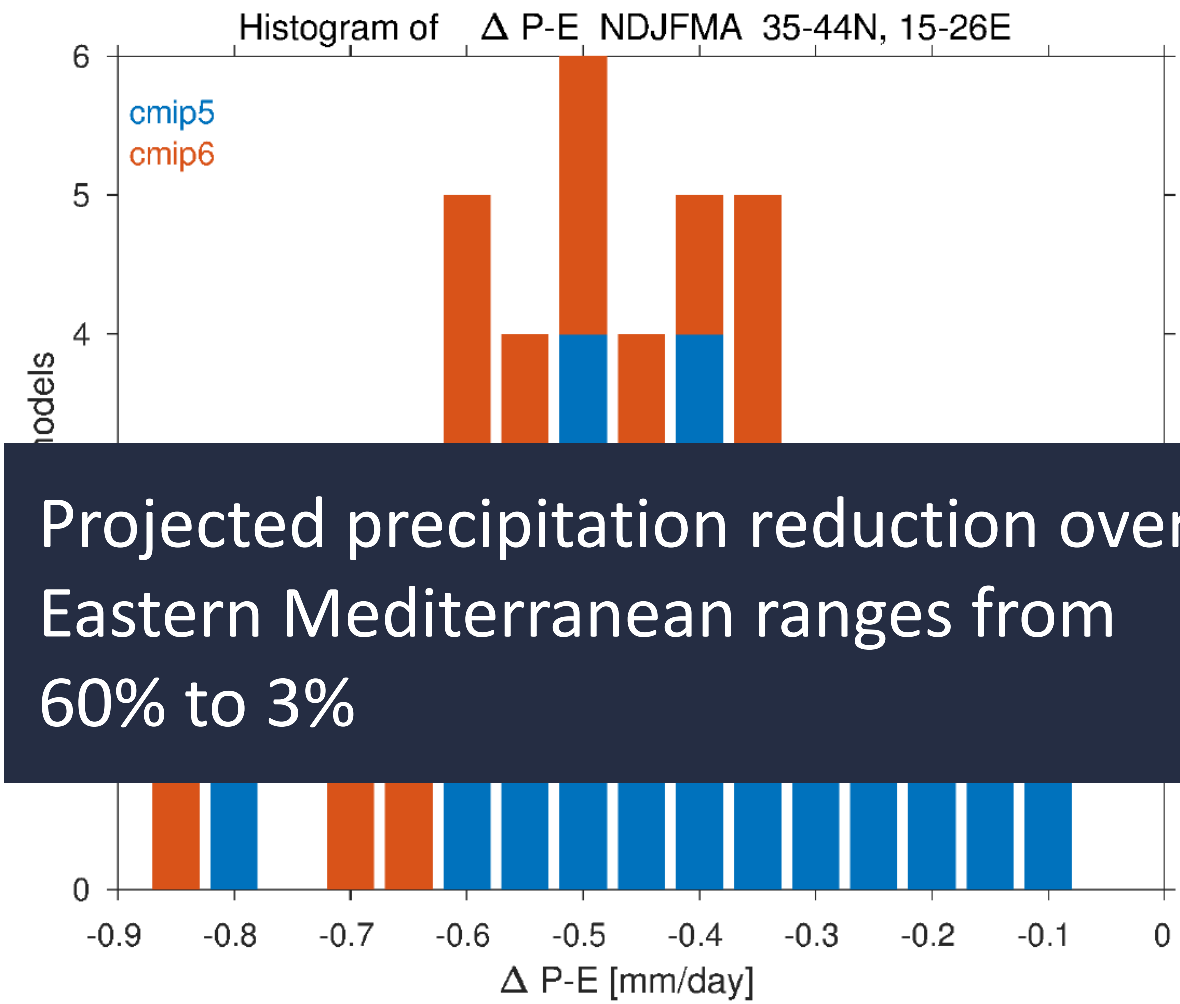

Projected precipitation reduction over Eastern Mediterranean ranges from 60% to 3%

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Research Questions:

Large scale drivers of drying:

What drives intermodel variability in projected drying trends?

To what extent is it related to intermodel uncertainty in large-scale zonal mean climate change?

To what extent is it related to intermodel uncertainty in dynamical vs. thermodynamical processes?

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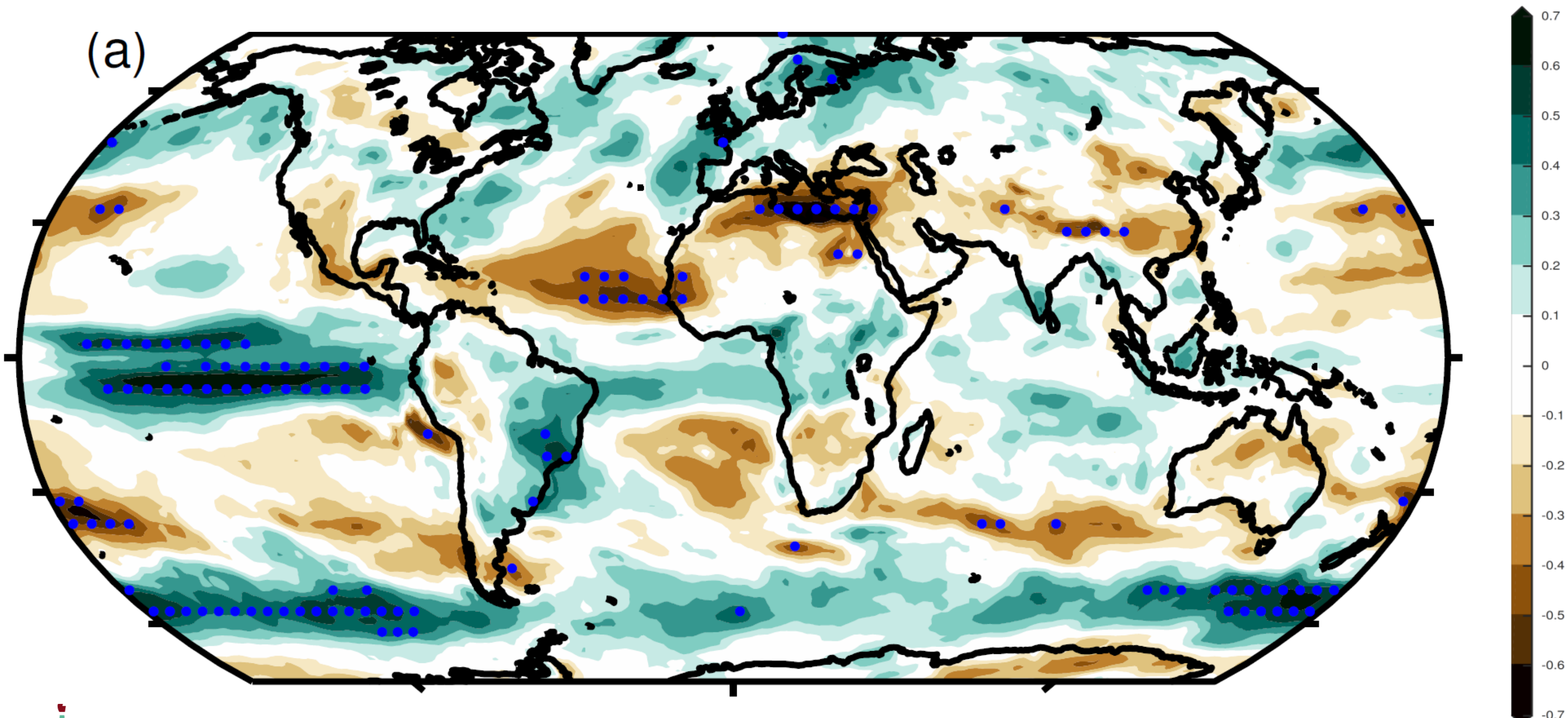
Is the spread among the models in precip. related to the spread in tropical stability?

Correlation of changes in end-of-century tropical static stability among 42 different models with changes in end-of-century precipitation at each gridpoint



Garfinkel et al 2020

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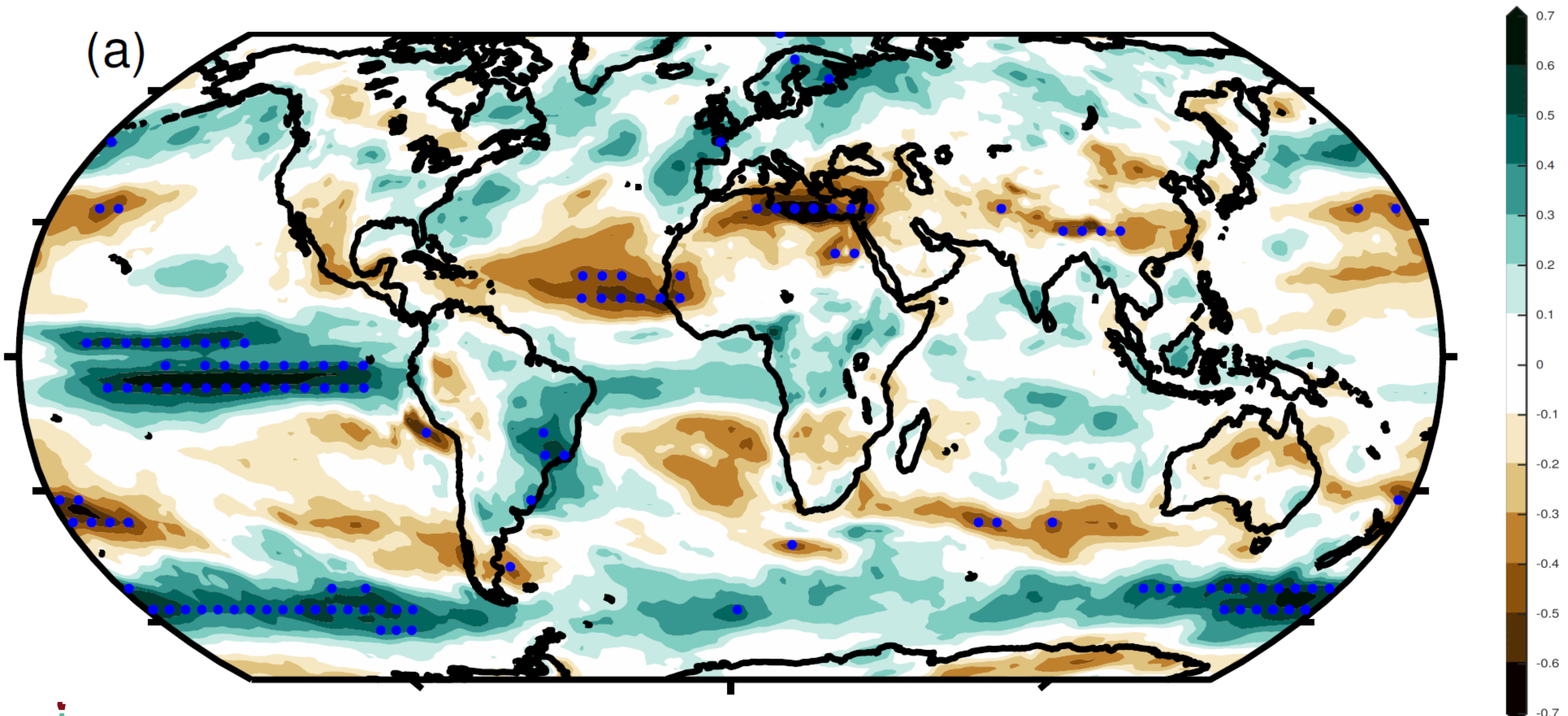
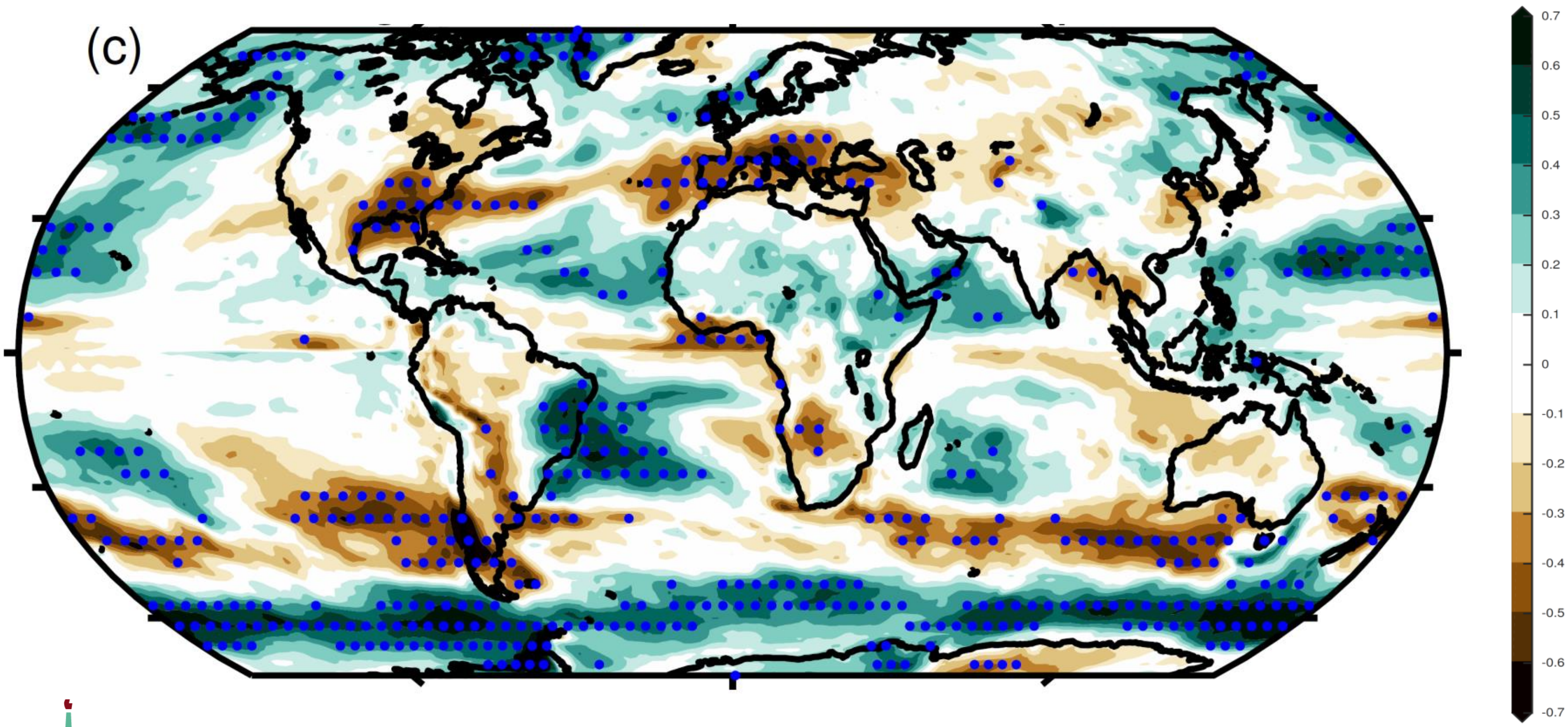
Correlation[$P_{2079\text{ to }2098} - P_{2009\text{ to }2028}$, $\text{stability}_{2079\text{ to }2098} - \text{stability}_{2009\text{ to }2028}$]



Garfinkel et al 2020

Is the spread in regional precip related to the spread in Hadley Cell widening?

Correlation of changes in end-of-century Hadley Cell subtropical expansion among 42 models with changes in end-of-century precipitation at each gridpoint



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Garfinkel et al 2020

Is the spread in regional precip related to the spread in Hadley Cell widening?

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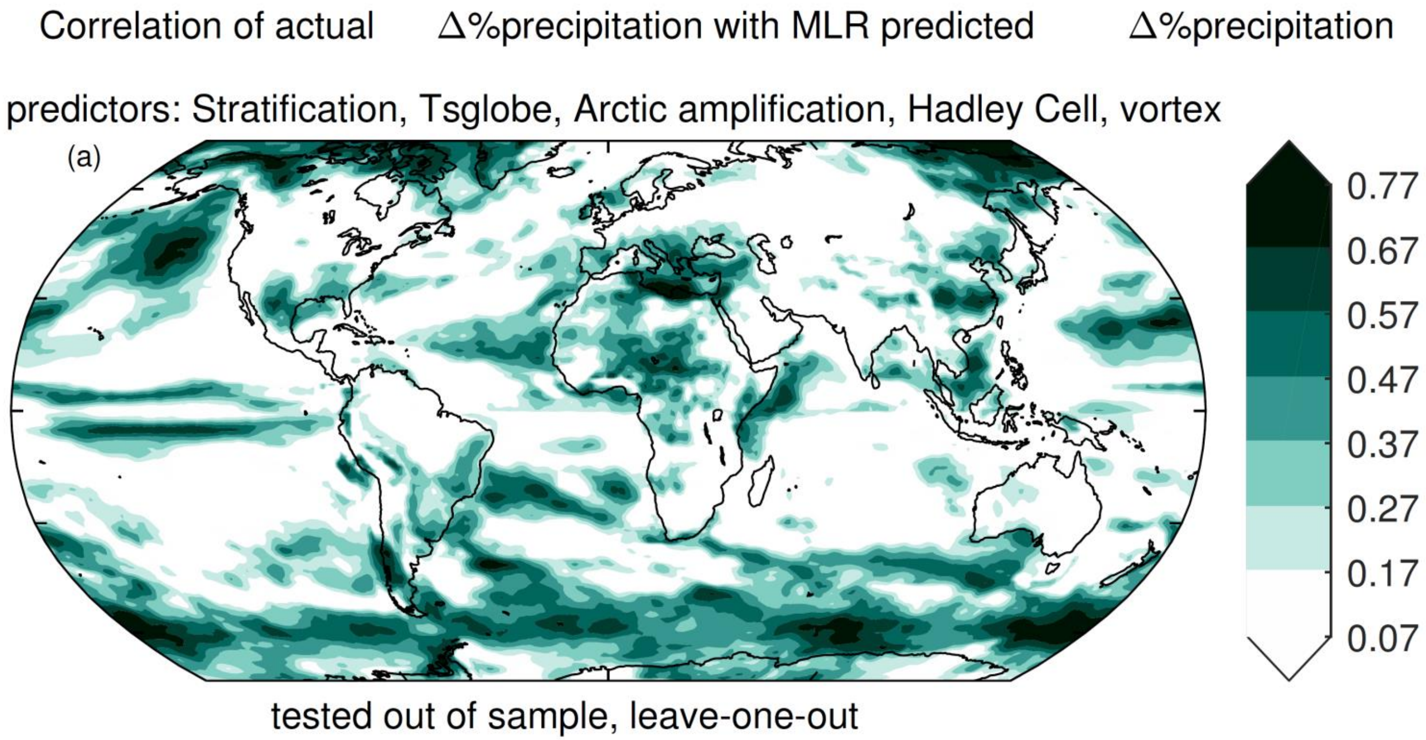
Similar for polar amplification, globally averaged surface temperature, and changes in polar stratospheric vortex

Overall, how much of the variance in regional precip. is associated with these five zonal mean processes?

Form a multiple linear regression model where these 5 processes are used to predict changes in precipitation at each gridpoint.



Garfinkel et al 2020

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Overall, how much of the variance in regional precip. is associated with these five zonal mean processes?

Form a multiple linear regression model where these 5 processes are used to predict changes in precipitation at each gridpoint.

Western US precipitation not associated with global factors, Eastern Mediterranean precipitation highly associated with global factors, and Western Mediterranean in between.

tested out of sample, leave-one-out

Garfinkel et al 2020

Conclusions from Garfinkel et al 2020

- Up to half of the inter-model spread in regional precipitation is related to the following large-scale drivers: Hadley Cell widening, polar amplification, stabilization of the tropical upper troposphere, and changes in the polar stratosphere.
- Large scales are most important over Eastern Mediterranean, southern Africa and Australia, and southern South America.
- Somewhat less important over East Asia, and Western Mediterranean.
- Global factors are unimportant over the interior of continents.

Garfinkel, C. I., Adam, O., Morin, E., Enzel, Y., Elbaum, E., Bartov, M., Rostkier-Edelstein, D., & Dayan, U. (2020). The Role of Zonally Averaged Climate Change in Contributing to Intermodel Spread in CMIP5 Predicted Local Precipitation Changes, *Journal of Climate*, *33*(3), 1141-1154.

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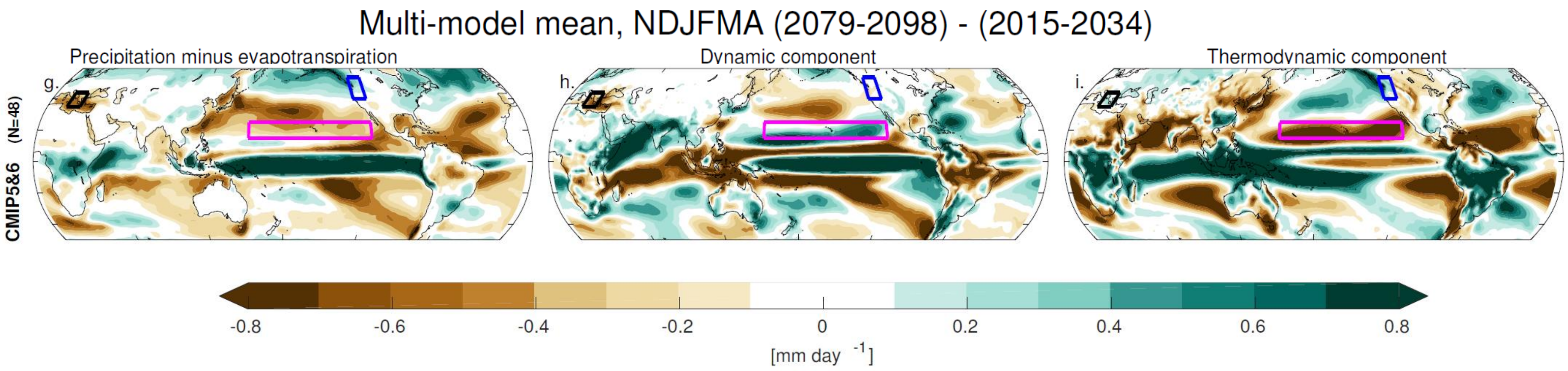
Multimodel mean projections: the future

Thermodynamic and dynamic budget of Seager et al 2014ab, 2019



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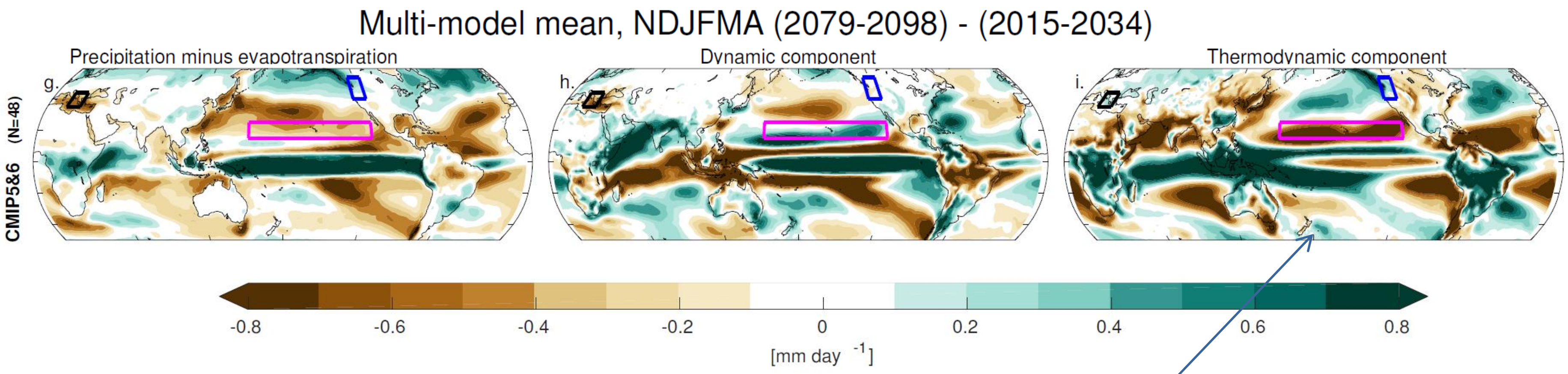

Changes in specific humidity, wind fixed:

1. Wet-get-wetter, dry-get-drier
2. Altered humidity gradients

Multimodel mean projections: the future

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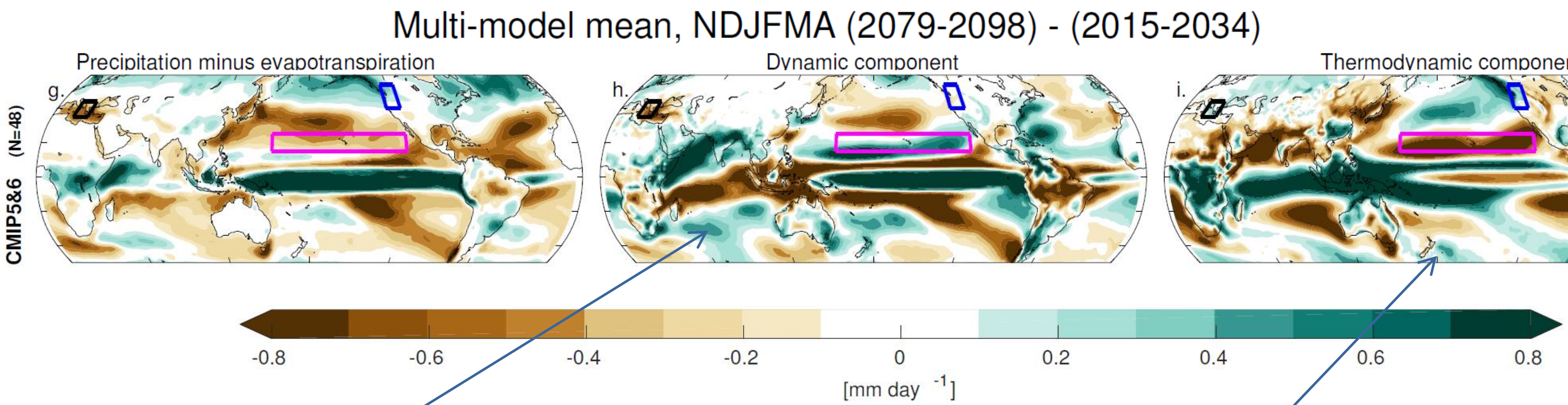

Changes in wind, specific humidity fixed:

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2. Changes in wind for advection

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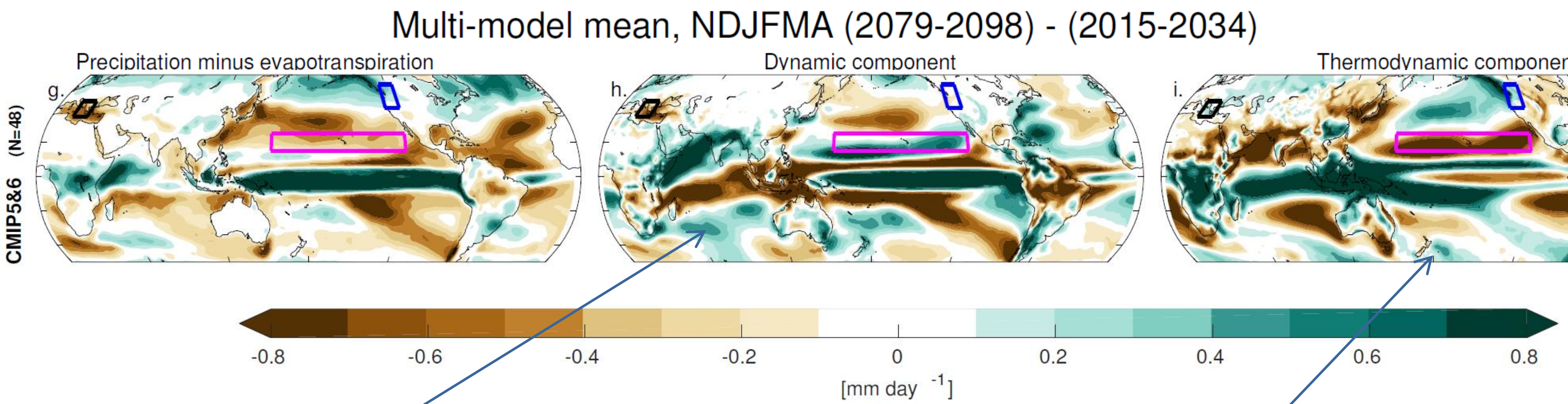

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Changes in specific humidity, wind fixed:

1. Wet-get-wetter, dry-get-drier
2. Altered humidity gradients

Both are important

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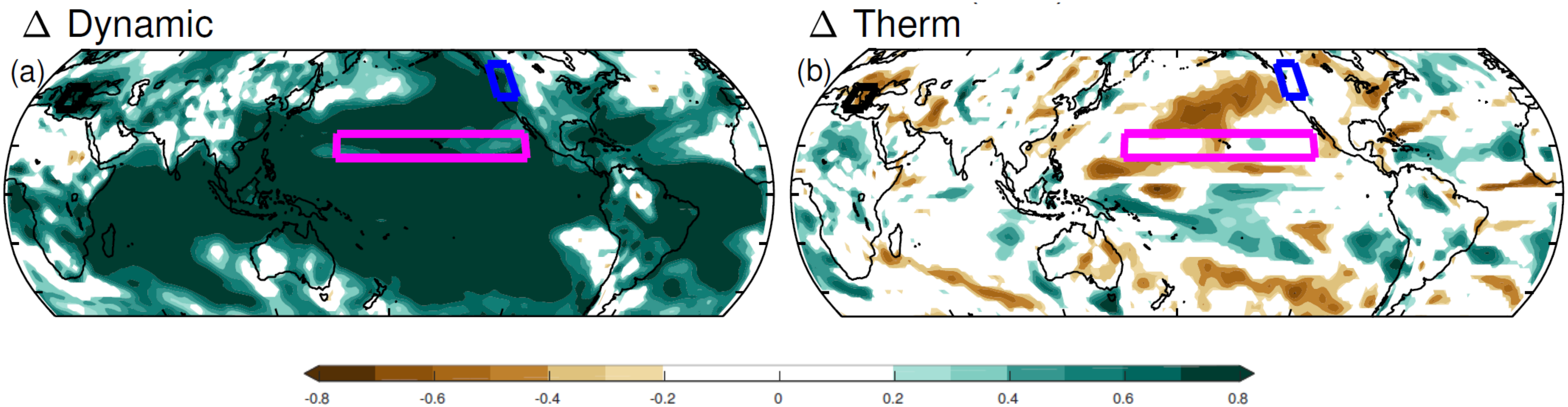
Model spread dominated by dynamic term

Across-model correlation coefficient between Δ(P−E) and



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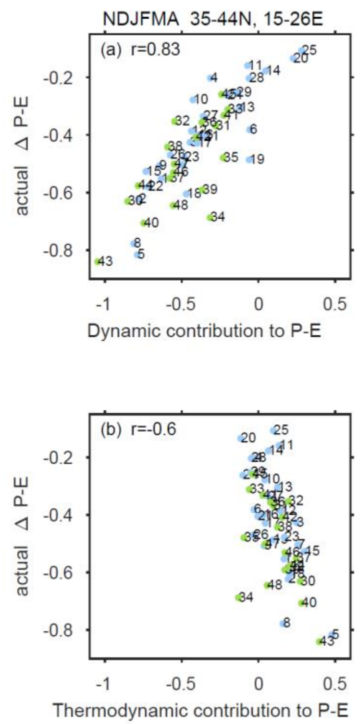

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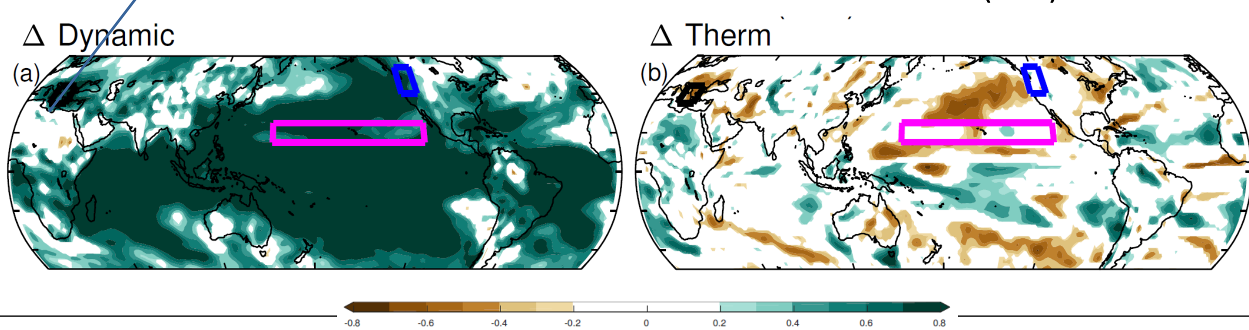

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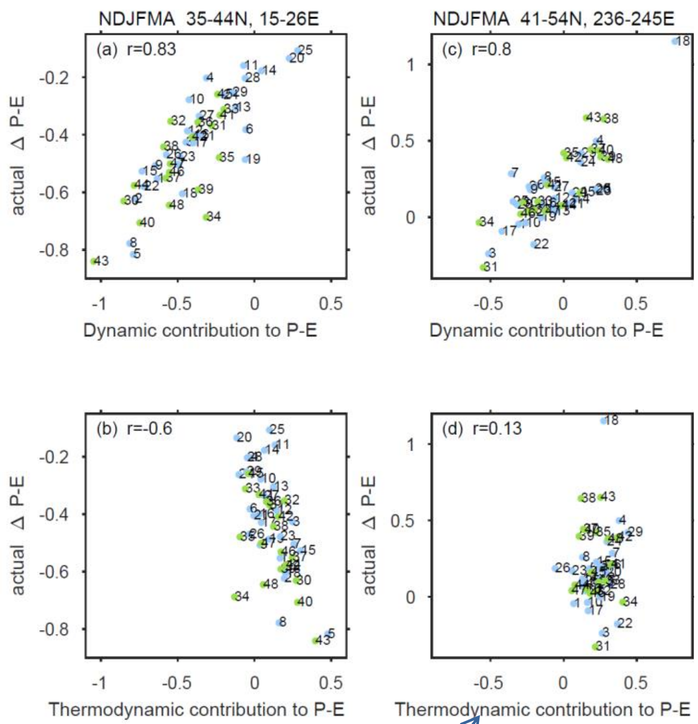

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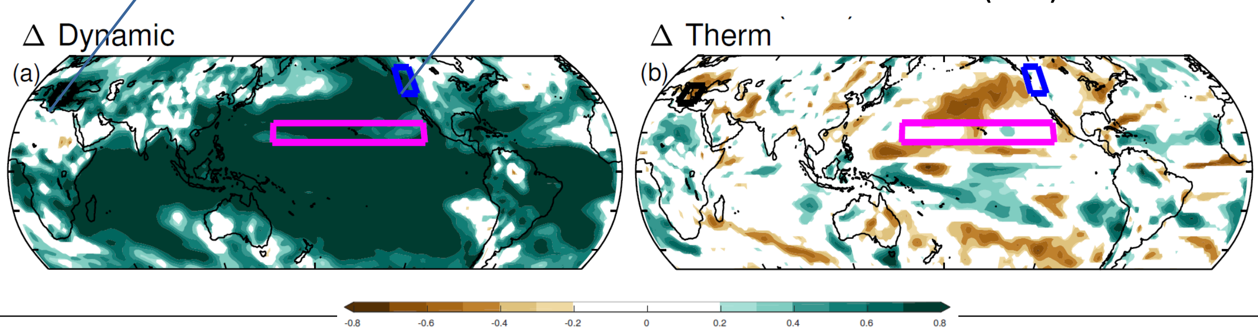

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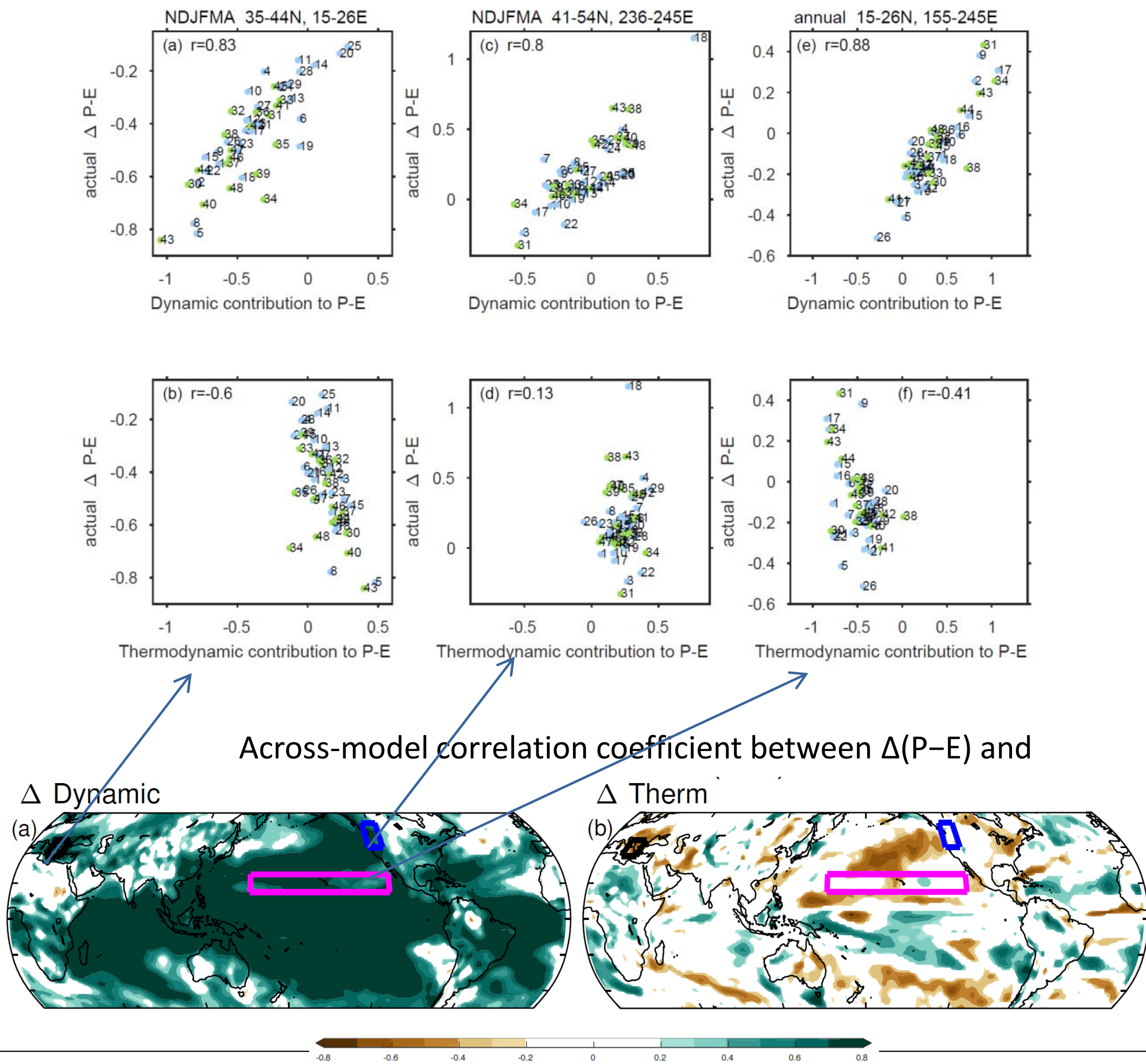
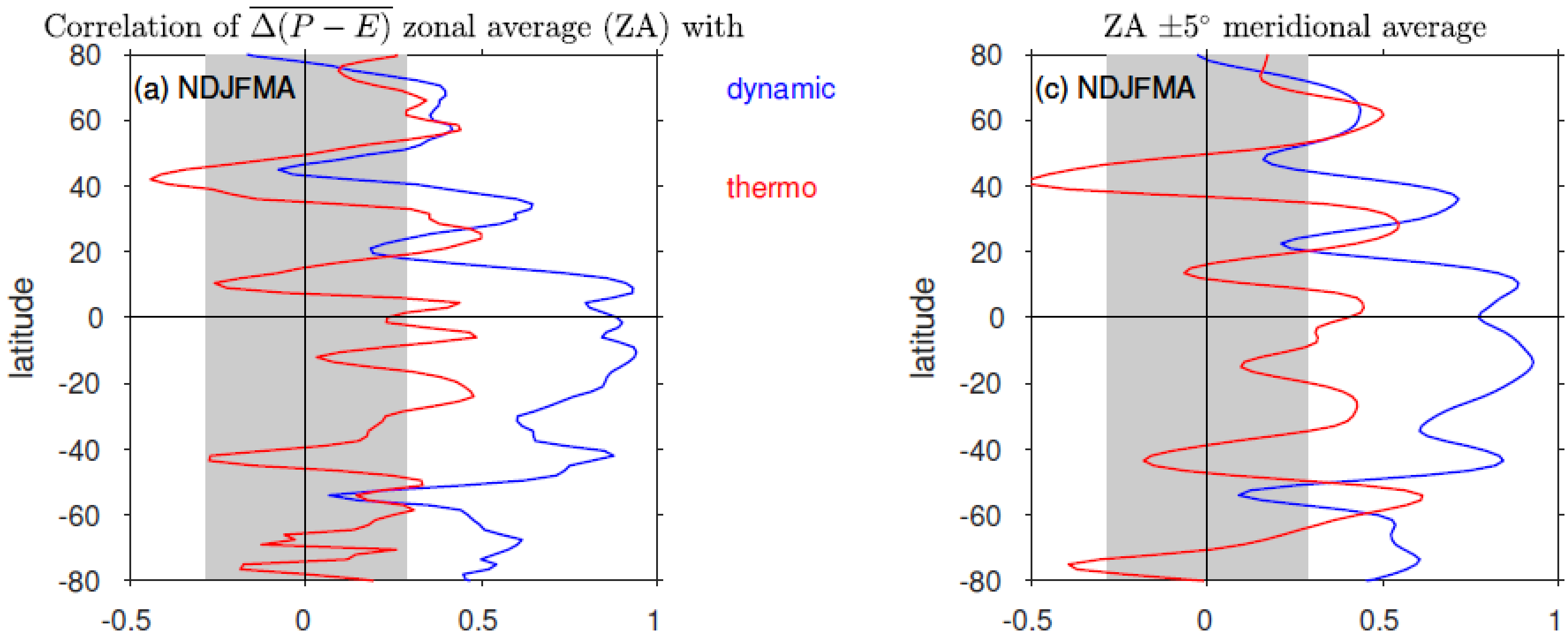


Model spread dominated by dynamic term even if we zonally and meridionally average



Conclusions from Elbaum et al in review

- While the thermodynamic dry-get-drier effect may be important for the multi-model mean response, it is not important for model spread.
- This irrelevance is not just due to dynamical stationary wave changes, as even if we zonally average the uncertainty from dynamical processes is still dominant
- Similar irrelevance over the subtropical oceans, perhaps the clearest example of dry-get-dryer when considering the multi-model mean.

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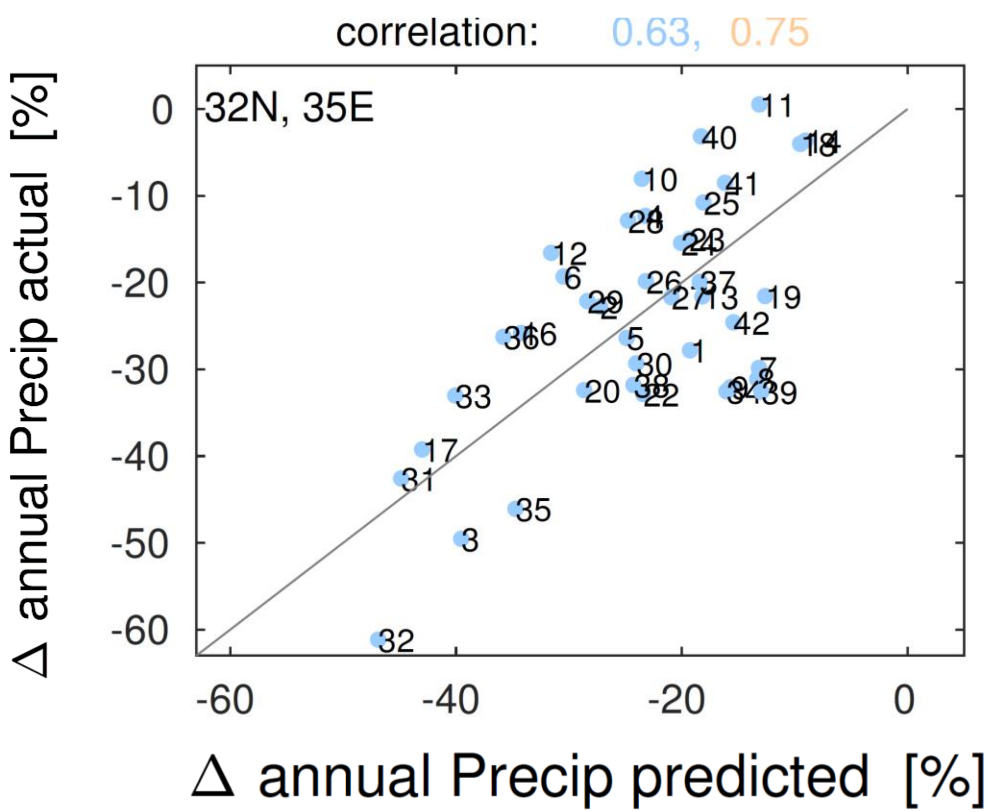
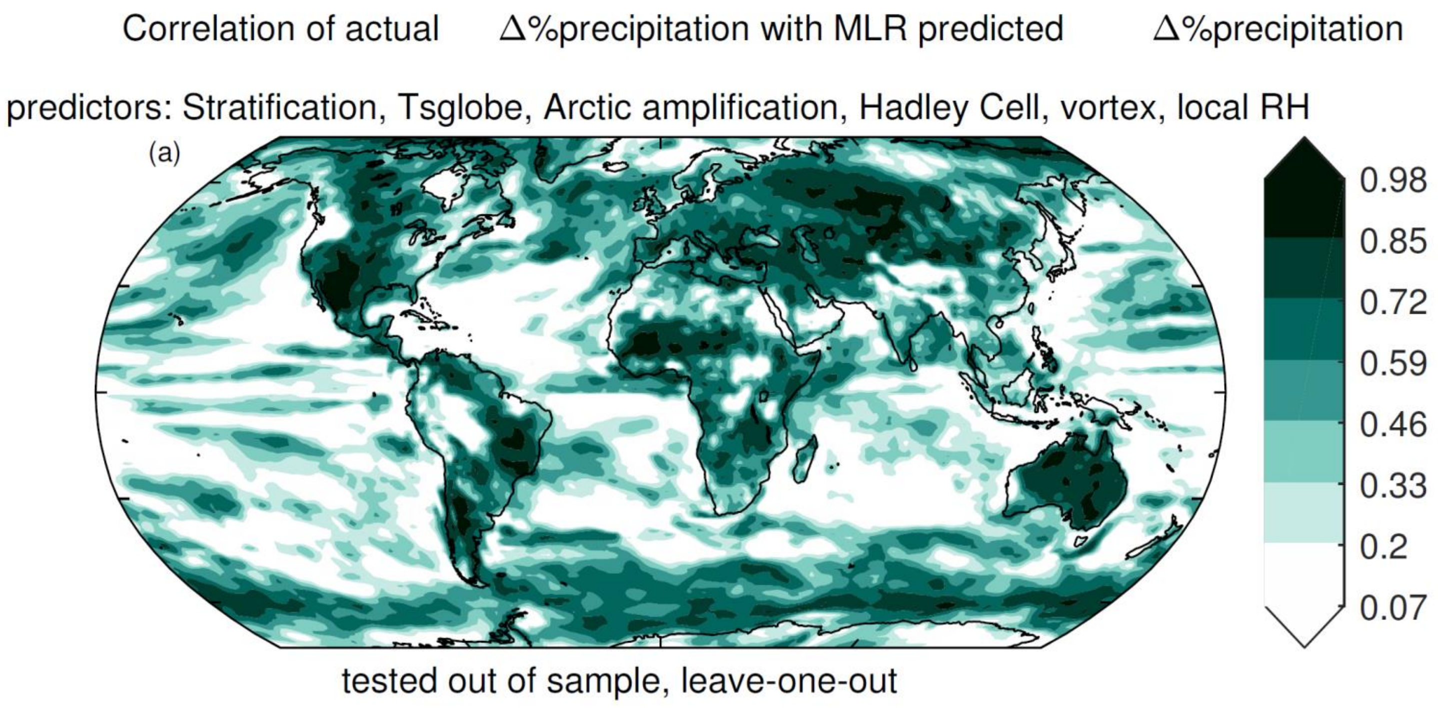
Taking Israel as an example:

Form a multiple linear regression model where these 5 processes are used to predict changes in precipitation at each gridpoint.



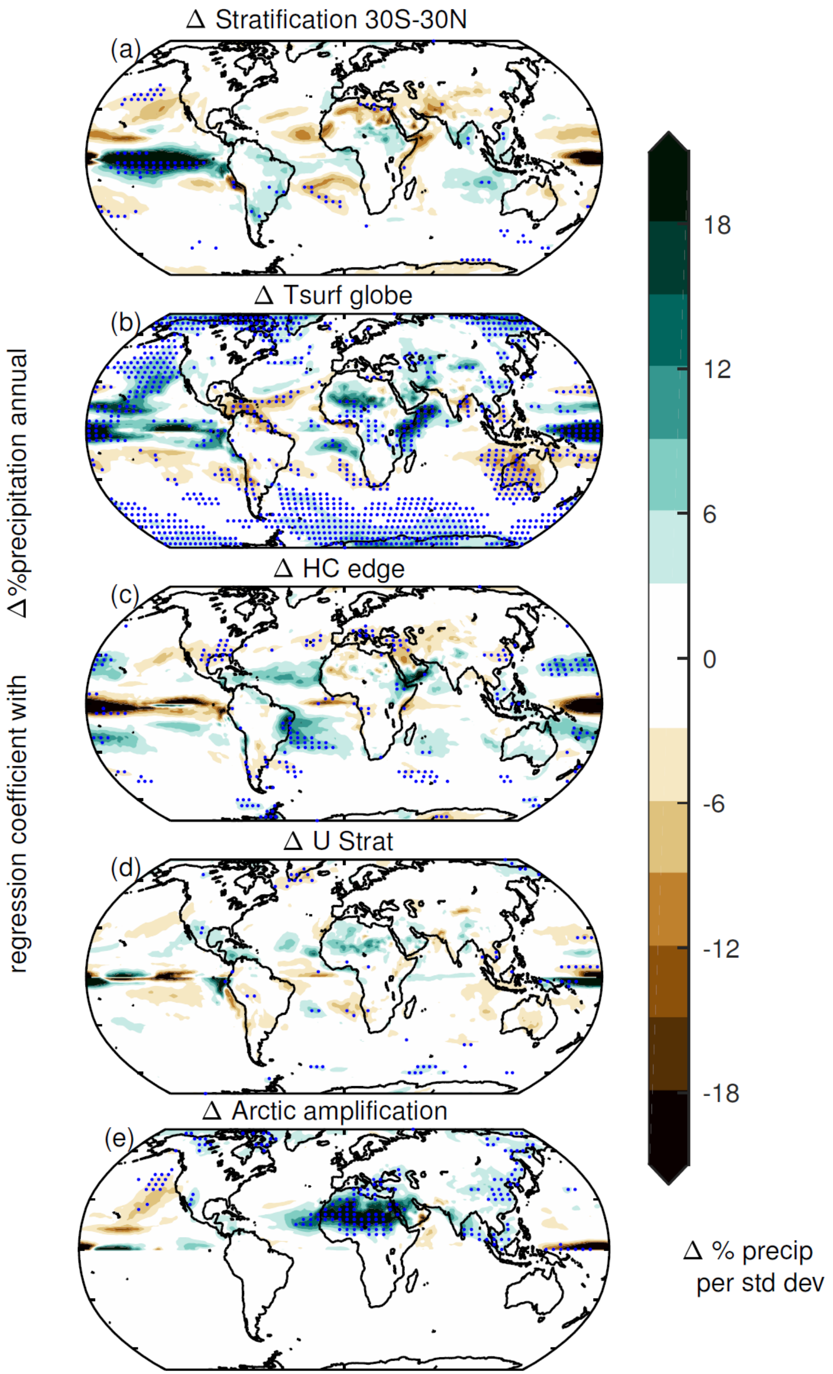
If local factors are added to MLR:



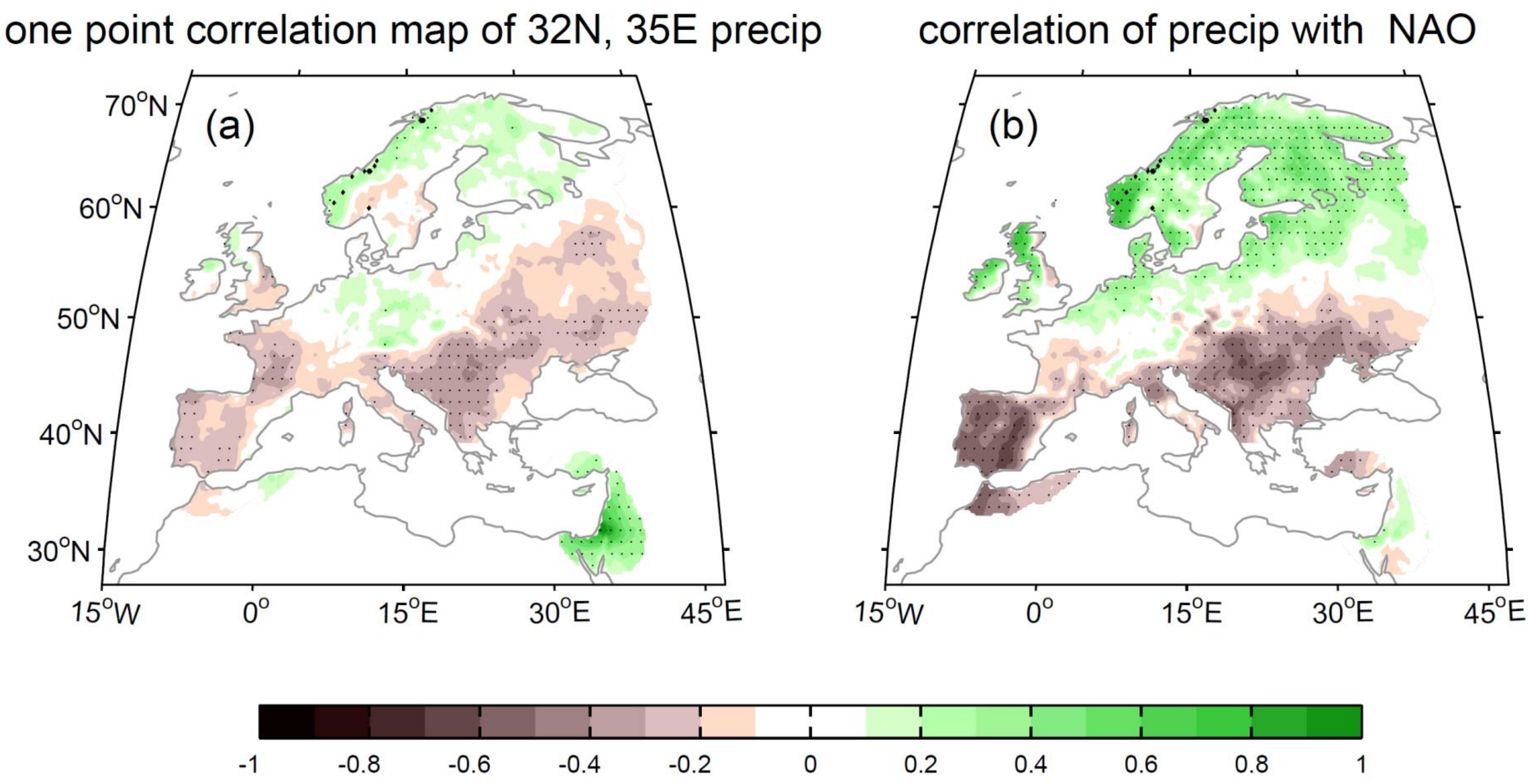
Which factor is most important?

For Eastern Mediterranean, changes in tropical static stability most important.

For Western Mediterranean, changes in Hadley Cell most important.



Differences between Eastern and Western Mediterranean evident on interannual timescales



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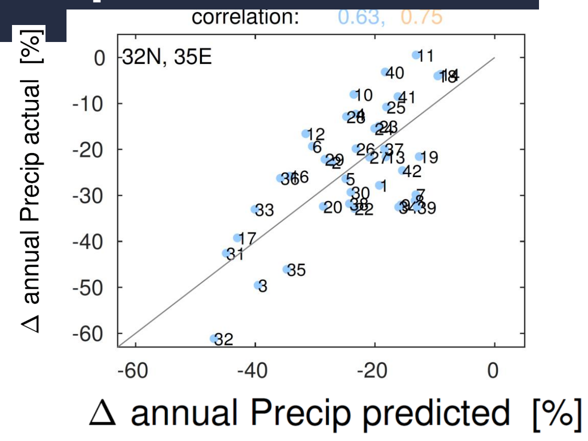

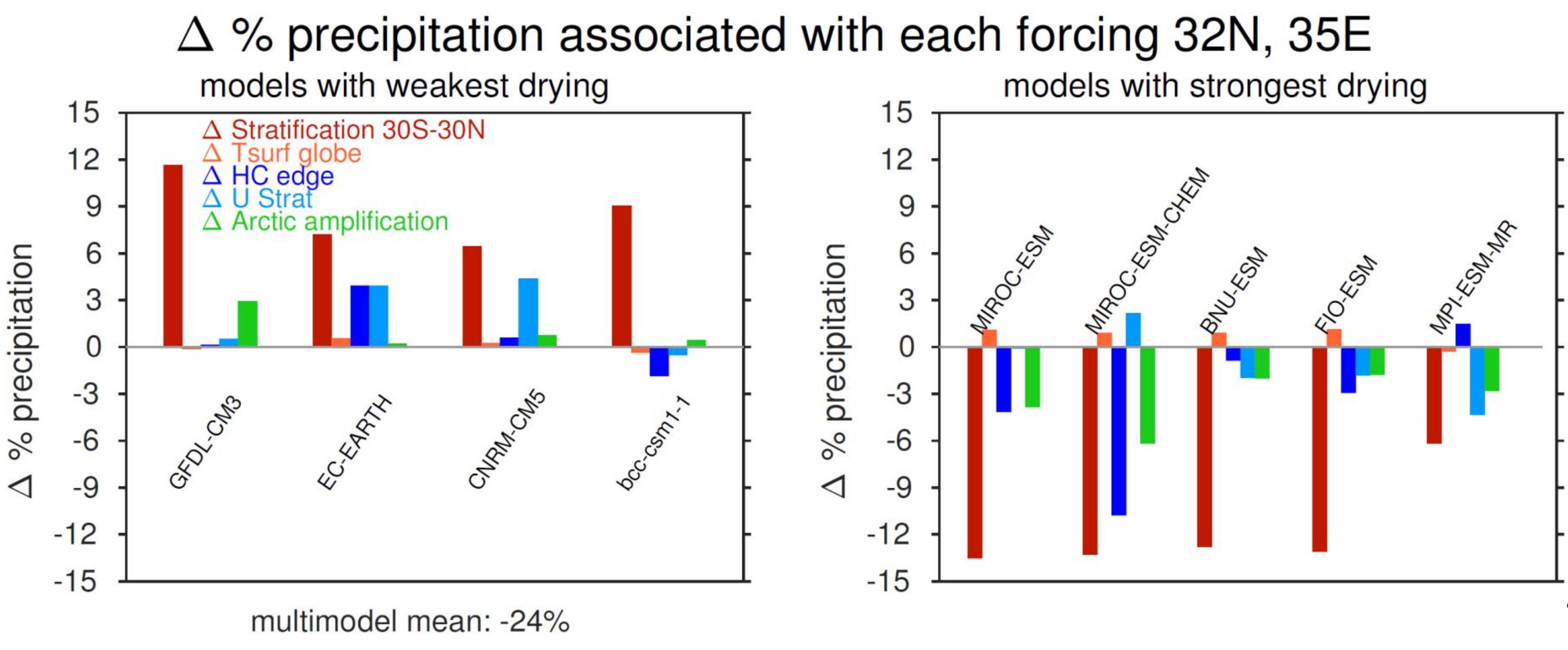

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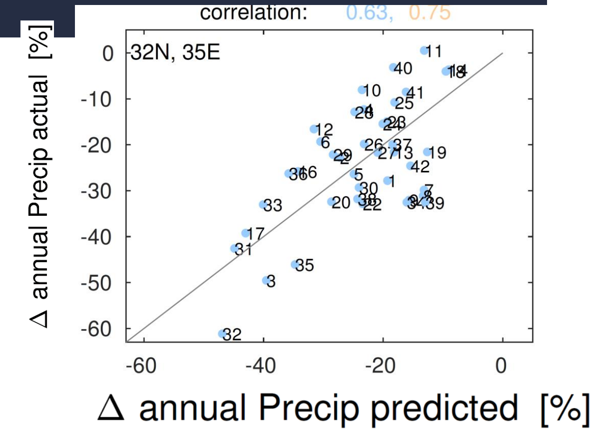
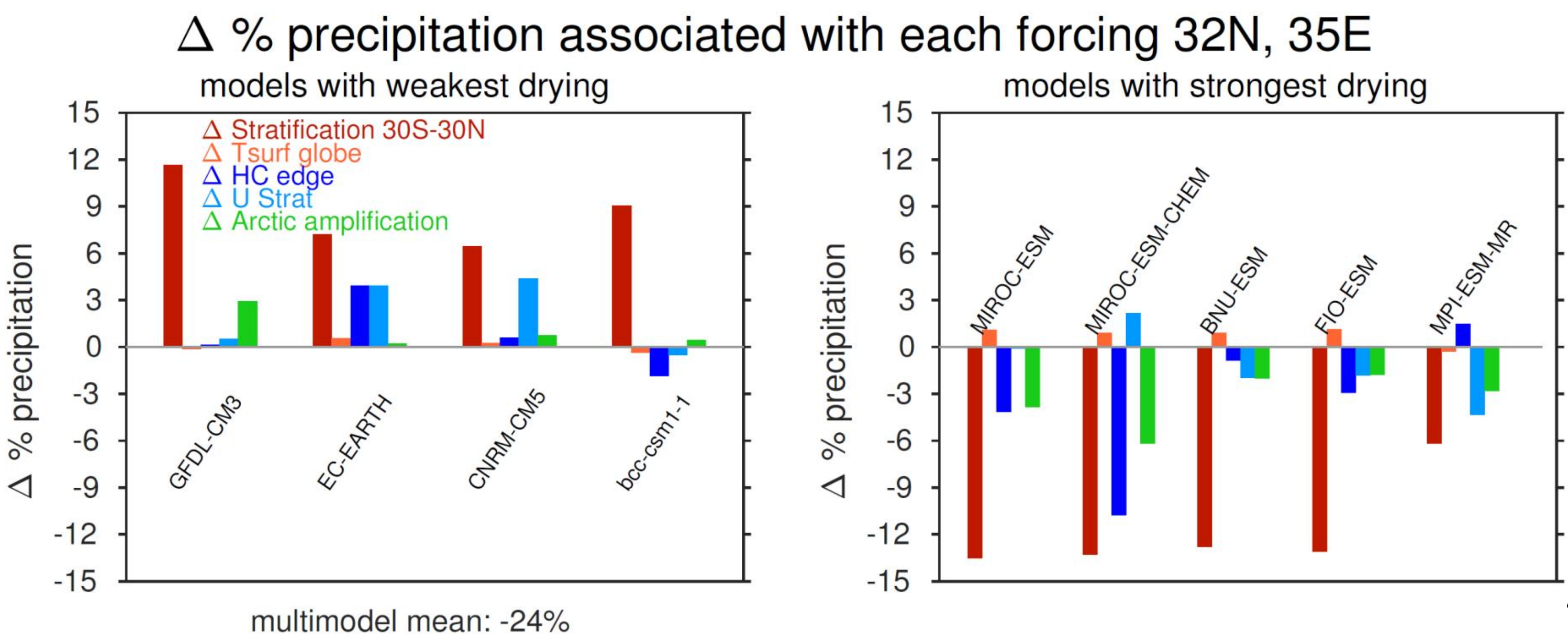




Our Question

How does the influence of variability in the strength of the stratospheric polar vortex on the tropospheric jet depend on its latitude?

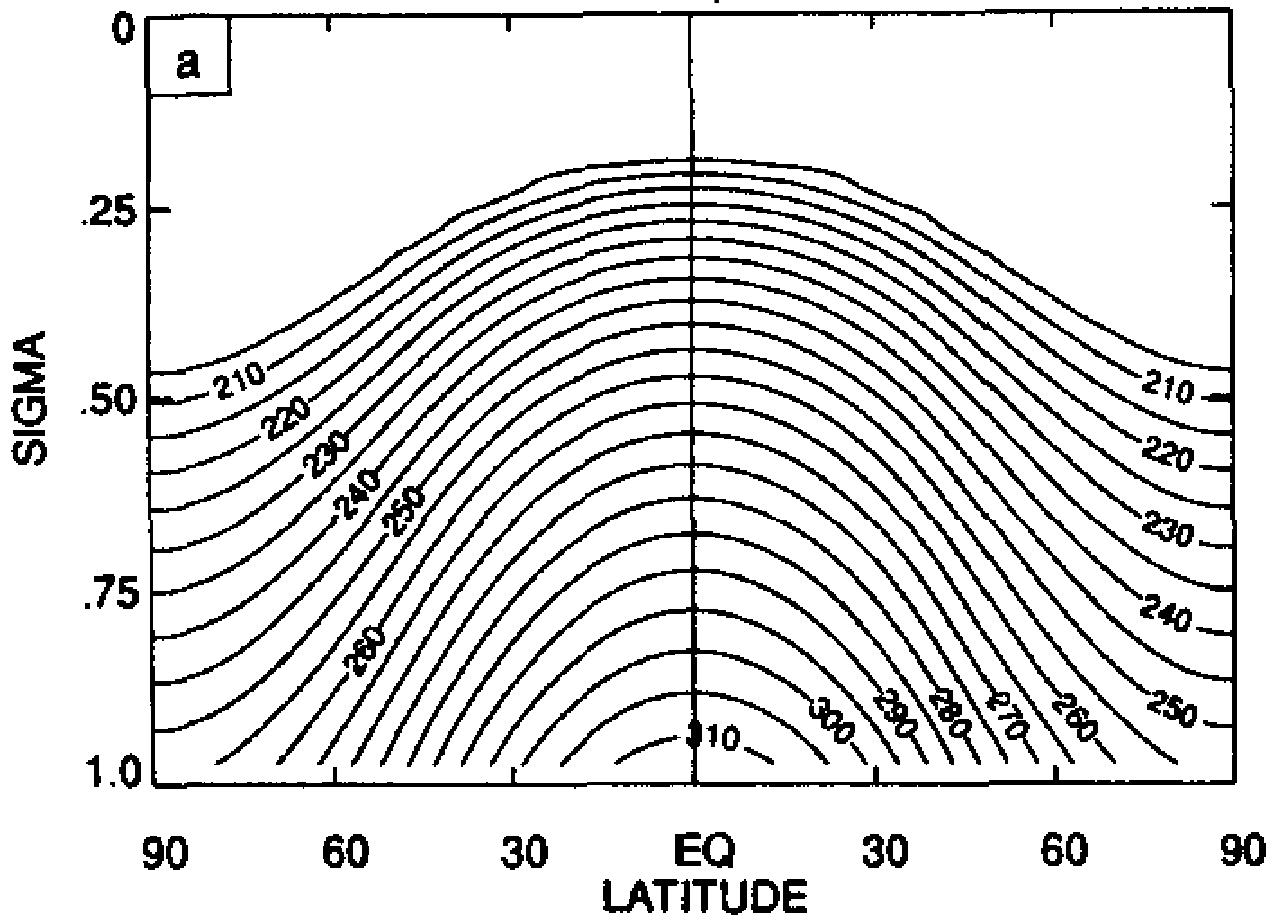
- How does the magnitude of the jet shift in response to a vortex change as the jet moves polewards?
- What aspect of jet variability can explain (or is consistent with) the magnitude of the observed jet shift?

In the SH, the response to a vortex intensifies as the tropospheric jet moves ***equatorwards*** from 50S to 40S.
In the NH, the response to a vortex intensifies as the tropospheric jet moves ***polewards*** from 30N to 40N.
Is there a simple underlying theory to explain this difference?

Dry Primitive Equation Model

- Dry GFDL model, T42, 40 levels
- Held-Suarez (1994)
- Vortex, as in Polvani and Kushner (2002)
- wavenumber-2 topography as in Gerber and Polvani (2009) – no regime behavior.

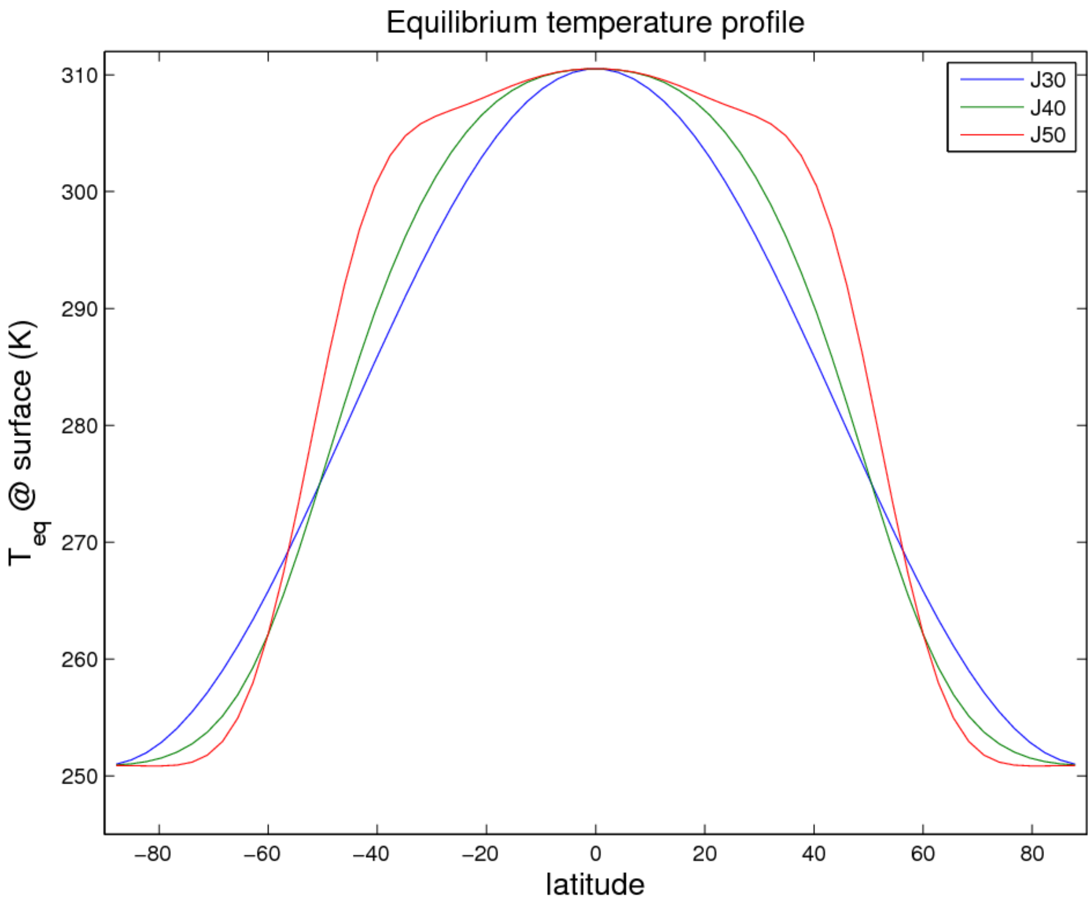
Relaxation Temperature Profile



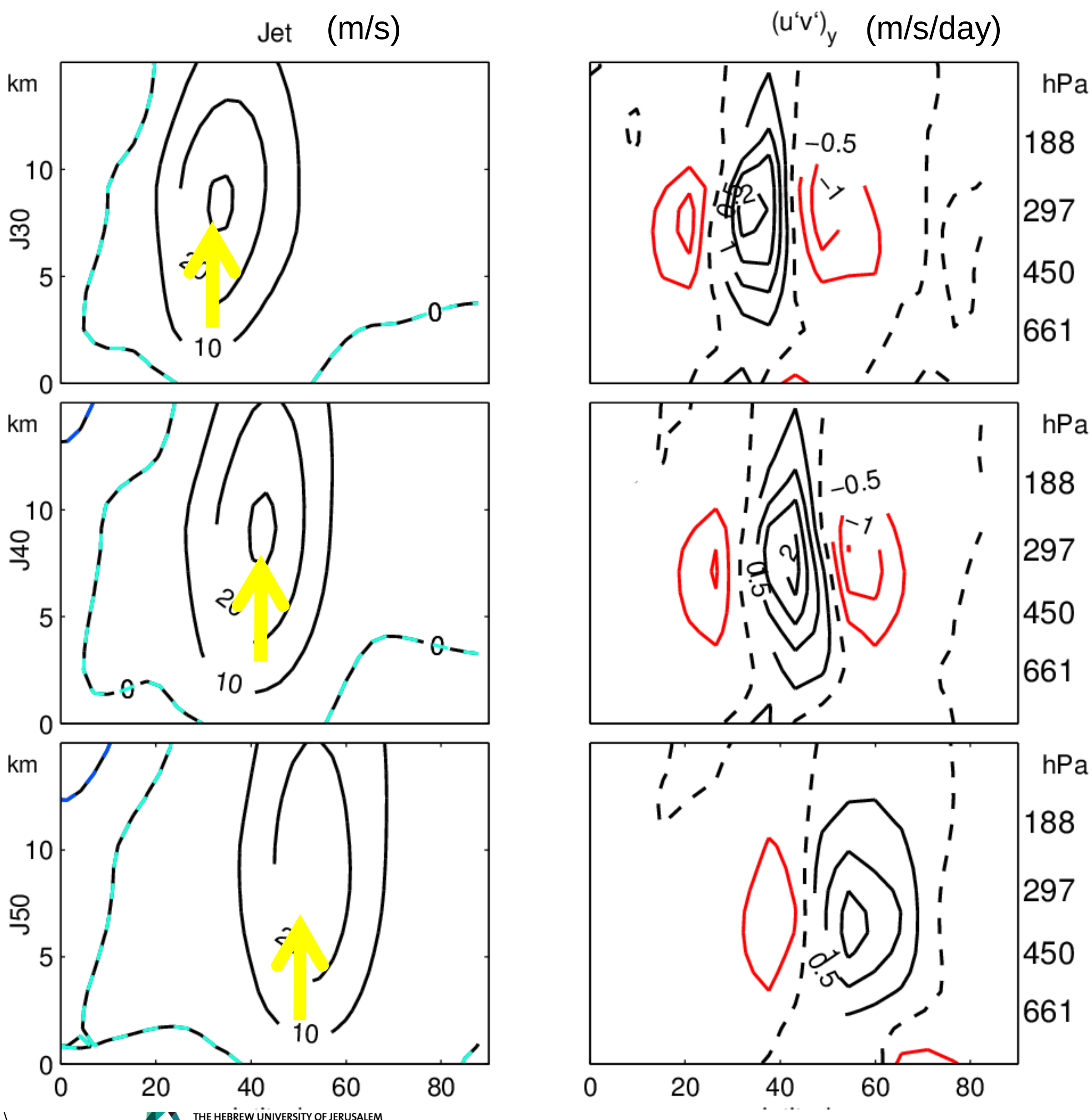
Held and Suarez 1994

Dry Primitive Equation Model

- Additional baroclonicity added to move the jet polewards and equatorwards.
- Equator-to-Pole temperature difference is held constant in all cases.
- Pairs of integrations done with and without a stratospheric vortex, for no-vortex tropospheric jet locations varying from 30S ("J30)" to 50S ("J50").



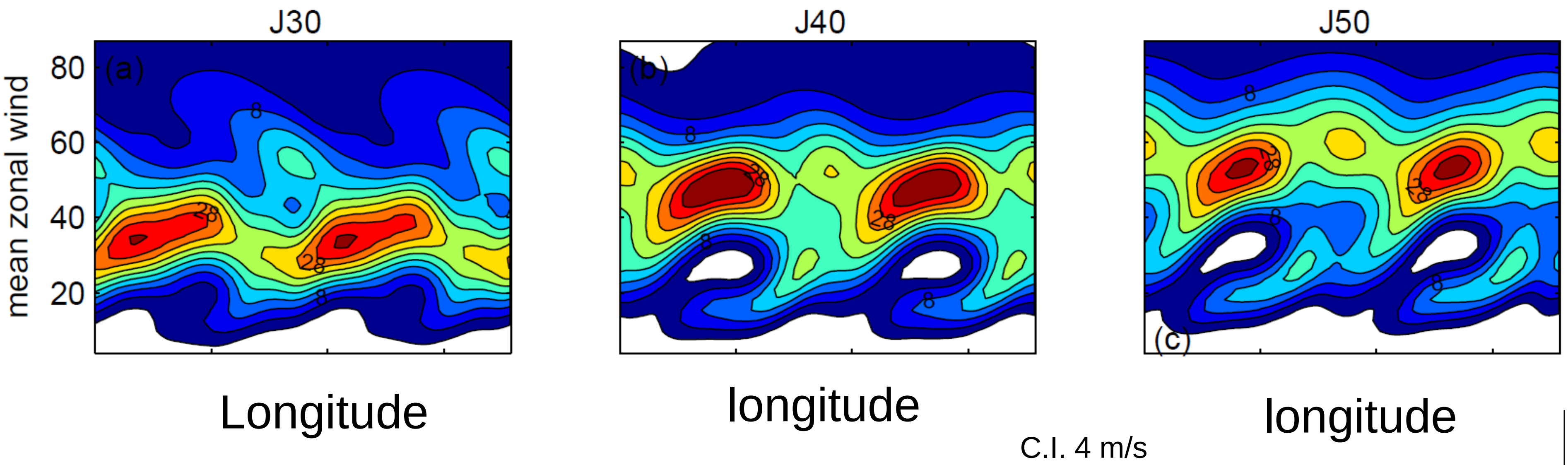
Control Climate in Dry Model



In all cases, the jet is eddy driven and is located near the latitude indicated by its name.

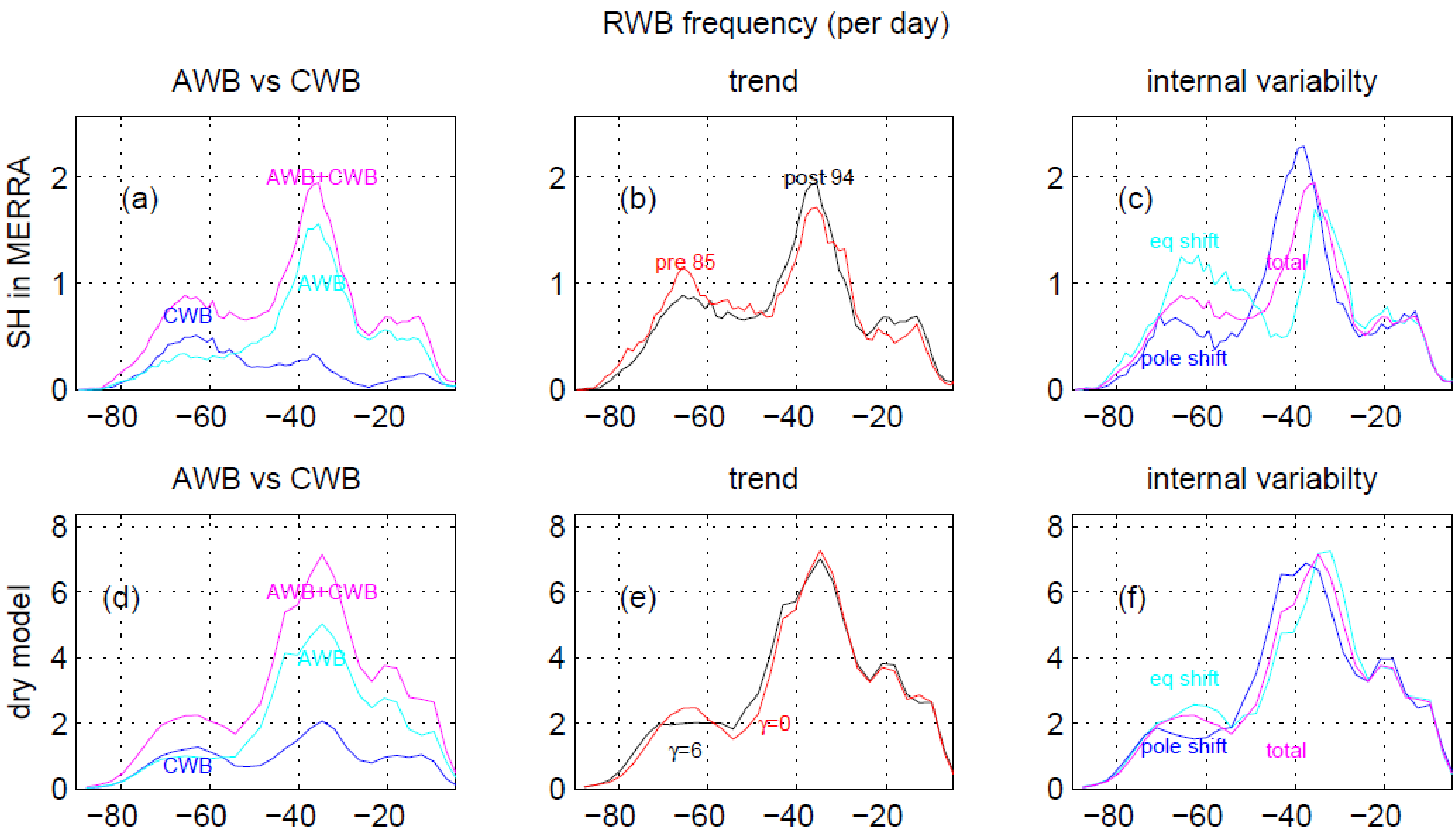
Lots of other runs have been performed to fill the parameter space

Control Climate in Dry Model



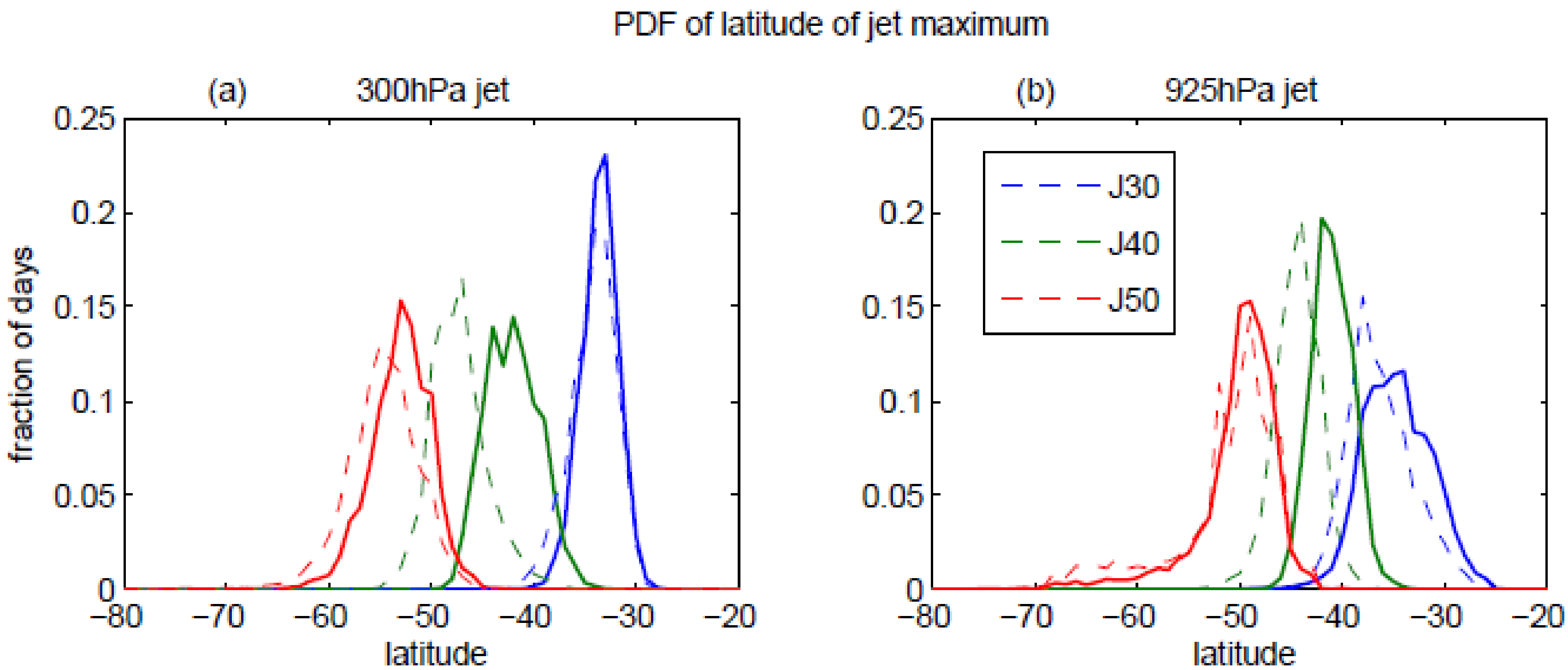
Mountain sets up strong zonal asymmetries, and thus an interesting testbed for analyzing Rossby wave breaking distribution.

Realistic Rossby wave breaking



Dry model captures the climatological distribution of RWB, as well as its interannual variability and its response to a polar vortex.

No Regime Behavior



Unlike in Polvani and Kushner 2002, jet distribution isn’t bimodal in any case (Chan and Plumb 2009).

Dashed – integration with a strong vortex
Solid – integration without a vortex

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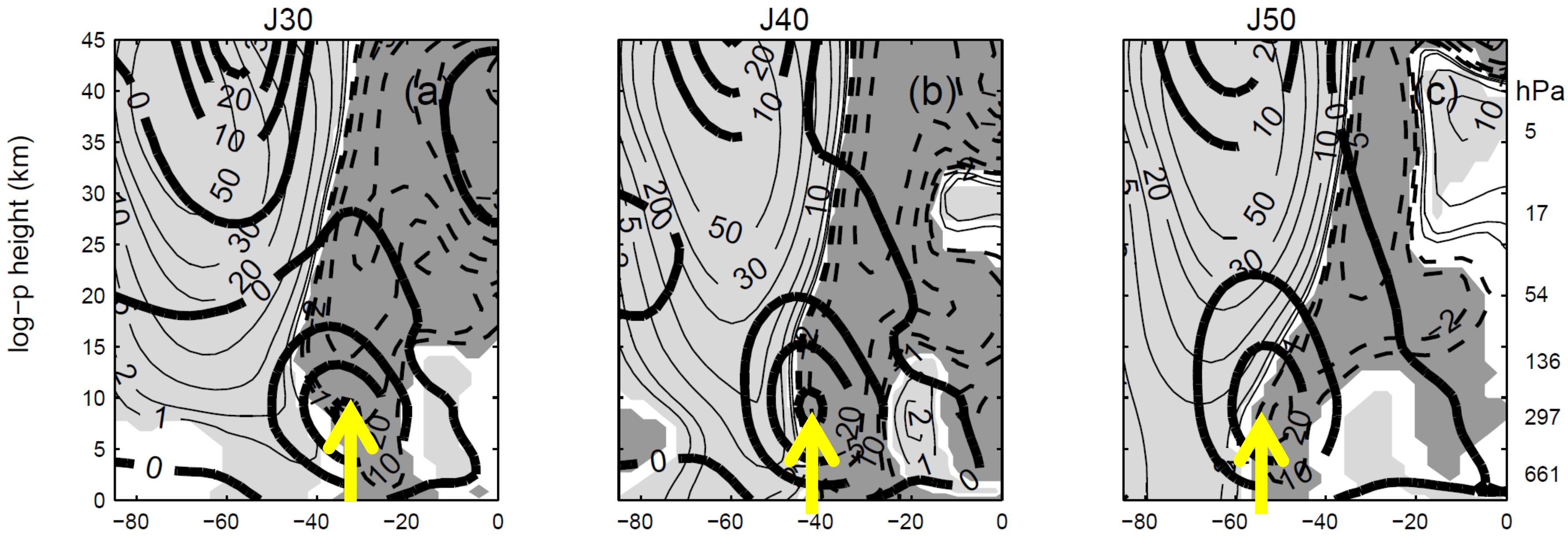
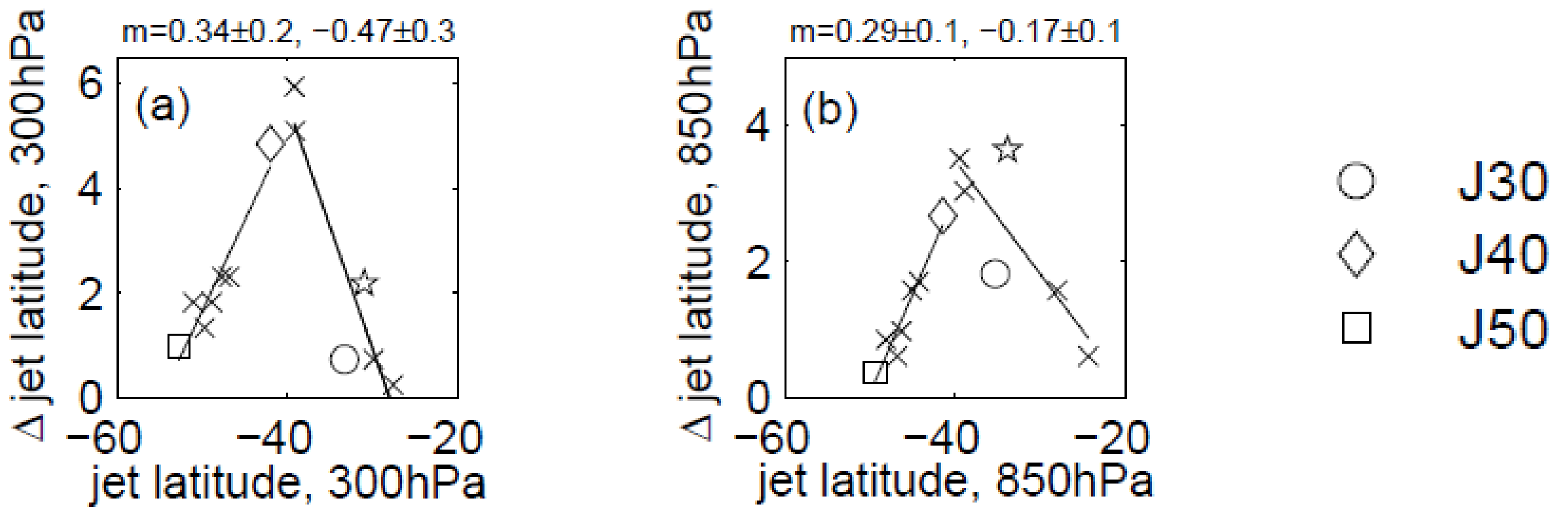
Control Run Jets



Control Zonal Wind – bold contours (m/s)
Zonal wind response to vortex – light contours and shading

- There is a poleward shift in all cases. The shift is weaker for J30/J50 and stronger for J40.
- This is consistent with the response in the NH Pacific and Atlantic sectors to vortex variability, and also with the SH response to Ozone and CO_2.

Response to Vortex



- Poleward shift in all cases.
- Jet latitude appears associated with the magnitude of the response.
- Weaker shift around 30 and 50, and stronger shift around 40.
- Effect between 30 and 40 consistent with response to anomalous vortex in NH, and effect between 40 and 50 consistent with range of responses to Ozone/CO_2 in SH in different comprehensive GCMs.
- Chevron, or inverted V, pattern
  - Why?

1. Introduction

2. Response to a Vortex

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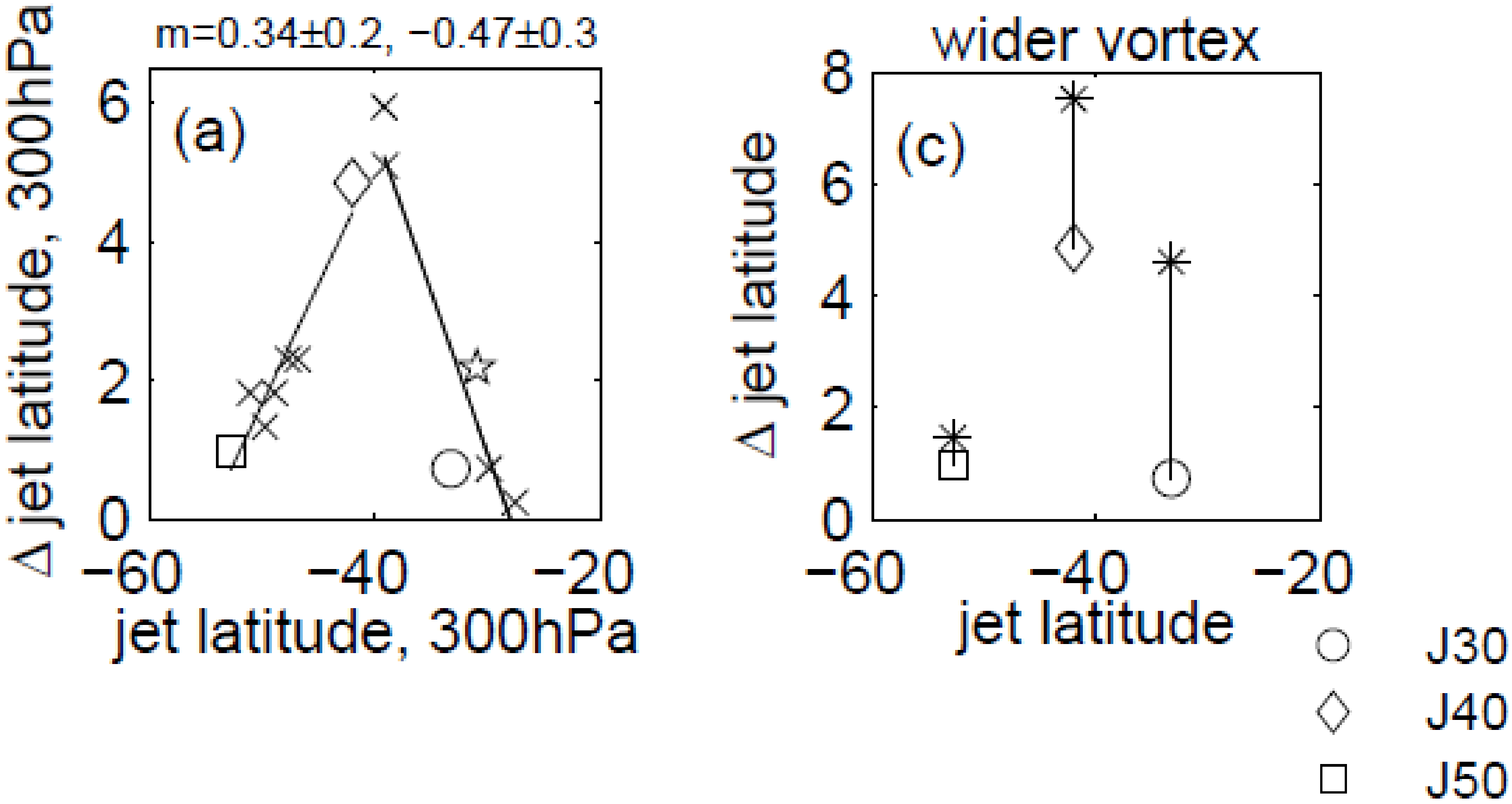
Possible Explanations for Magnitude of Jet Shift

- Proximity to Vortex (J30 vs J40)
- Jet variability associated with J40 leads to a stronger response:
    - Eddy Length Scale
    - Eddy Phase speed
    - Eddy Momentum Flux
    - Eddy Heat Flux
    - Eddy feedback strength of the eddy driven jet

Sensitivity to vortex width

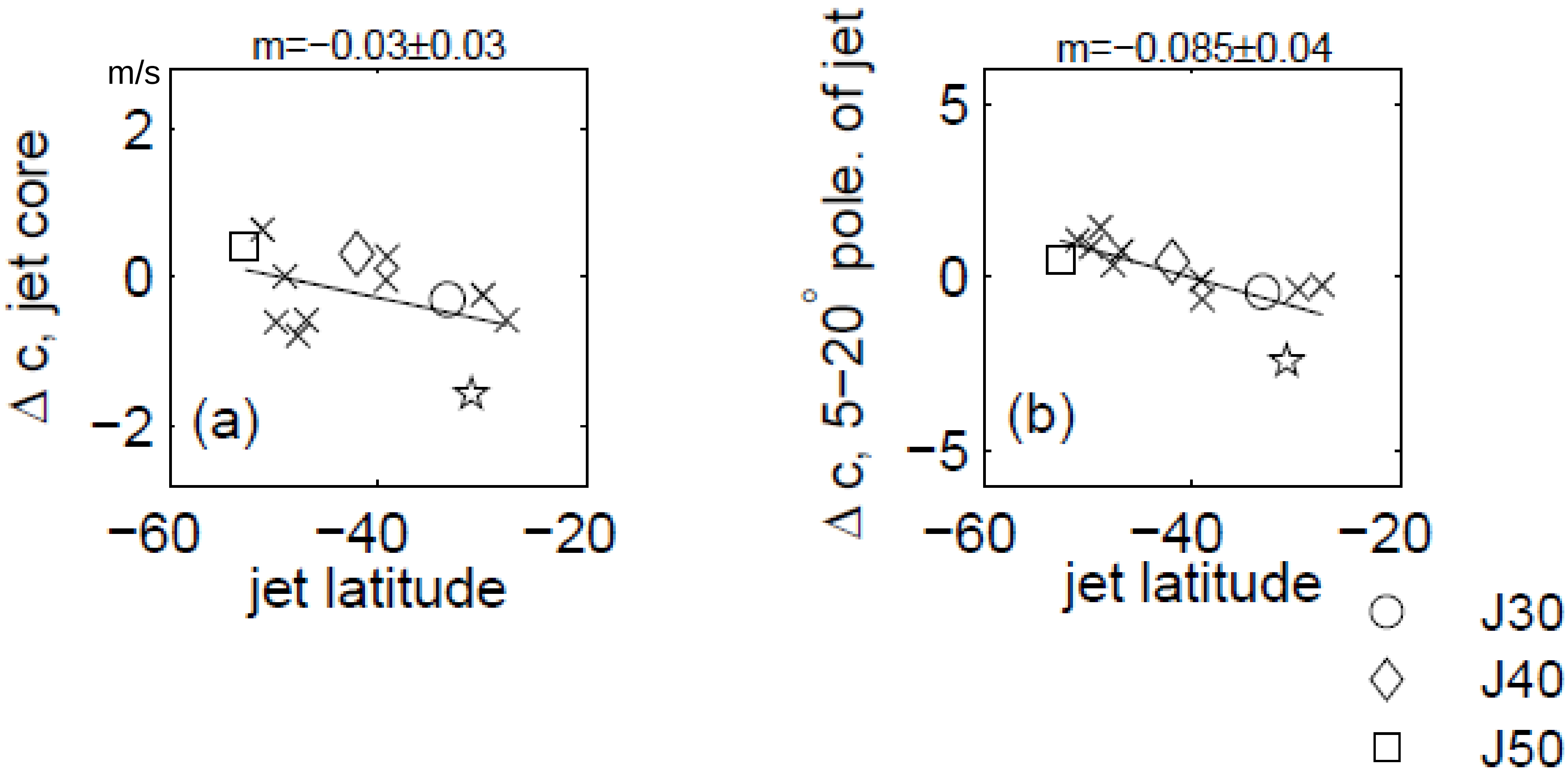


Even after we change the polar vortex width so that it is broader, we find a weaker shift for J30 and J50, and a stronger shift for J40.

Possible Explanations for Magnitude of Jet Shift

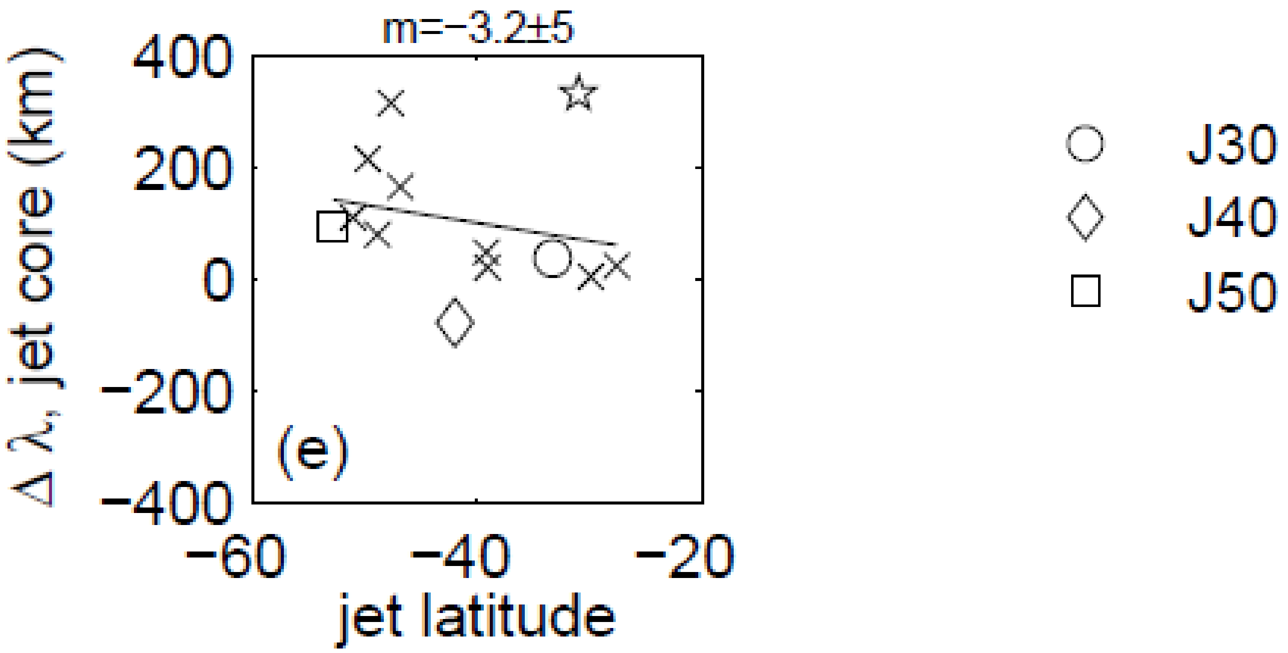
- ~~External forcing associated with vortex projects most strongly onto J40.~~
- Jet variability associated with J40 leads to a stronger response:
    - Eddy heat flux
    - Eddy length scale
    - Eddy phase speed
    - PV inversion
    - Eddy Momentum Flux
    - Eddy feedback strength of the eddy driven jet

Unsuccessful Explanation for Magnitude of Shift (1)



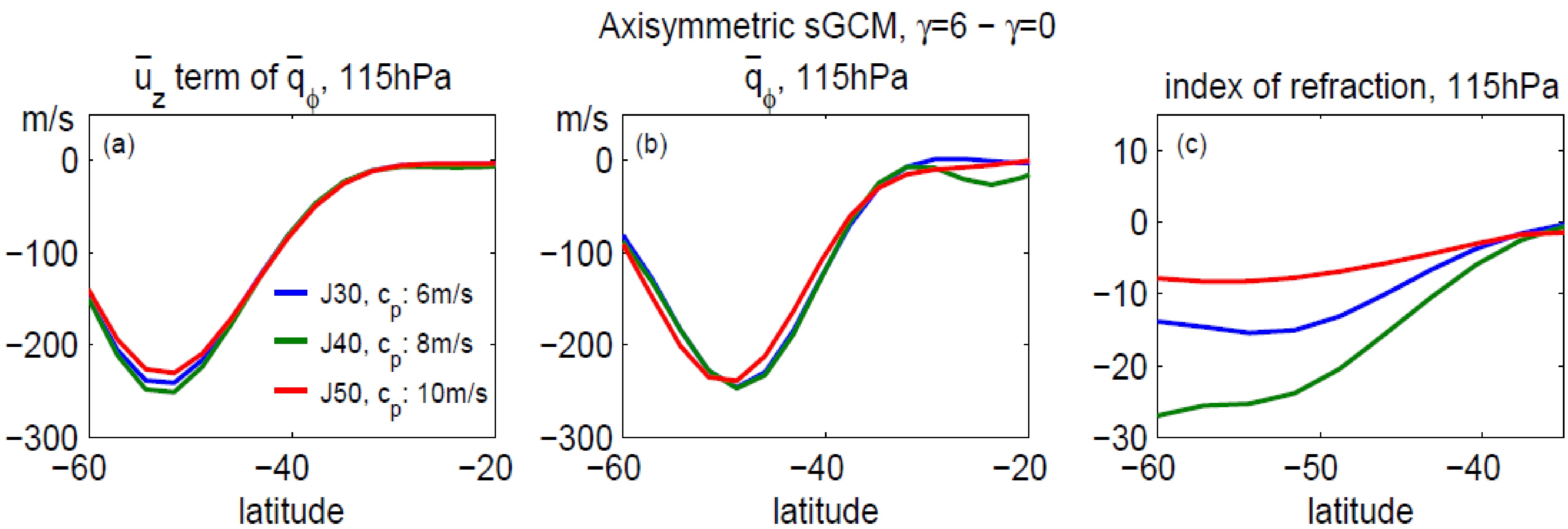
Changes in eddy phase speed (Chen and Held, 2007) can't explain this effect.

Unsuccessful Explanation for Magnitude of Shift (2)



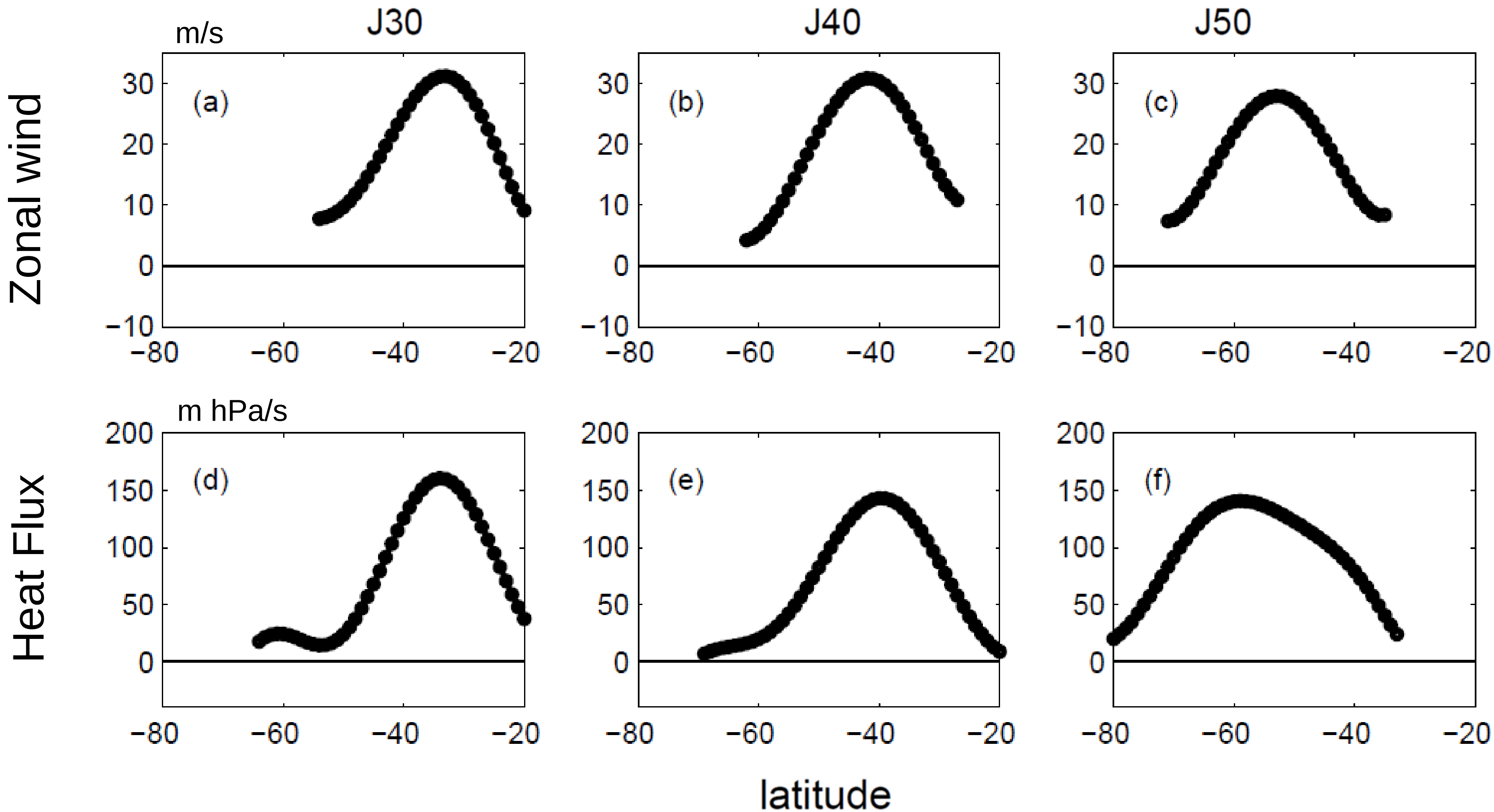
Changes in eddy zonal length scales (Kidston et al, 2010) also can't explain this effect.

Unsuccessful Explanation for Magnitude of Shift (3)



PV inversion arguments also can't explain this effect. Index of refraction arguments are somewhat consistent.

Eddy Fluxes in Control Run



Similar jet speed and heat flux in all cases

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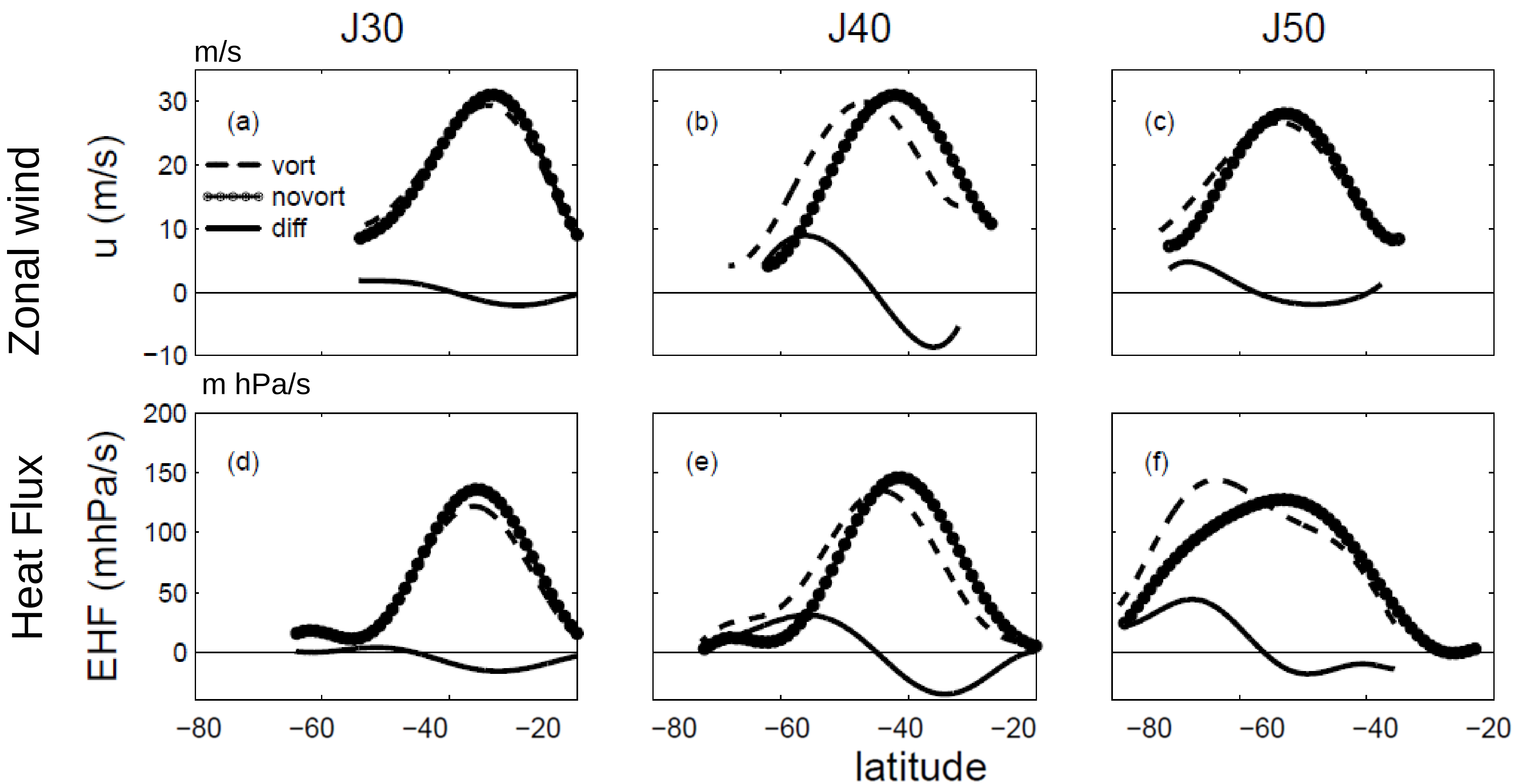
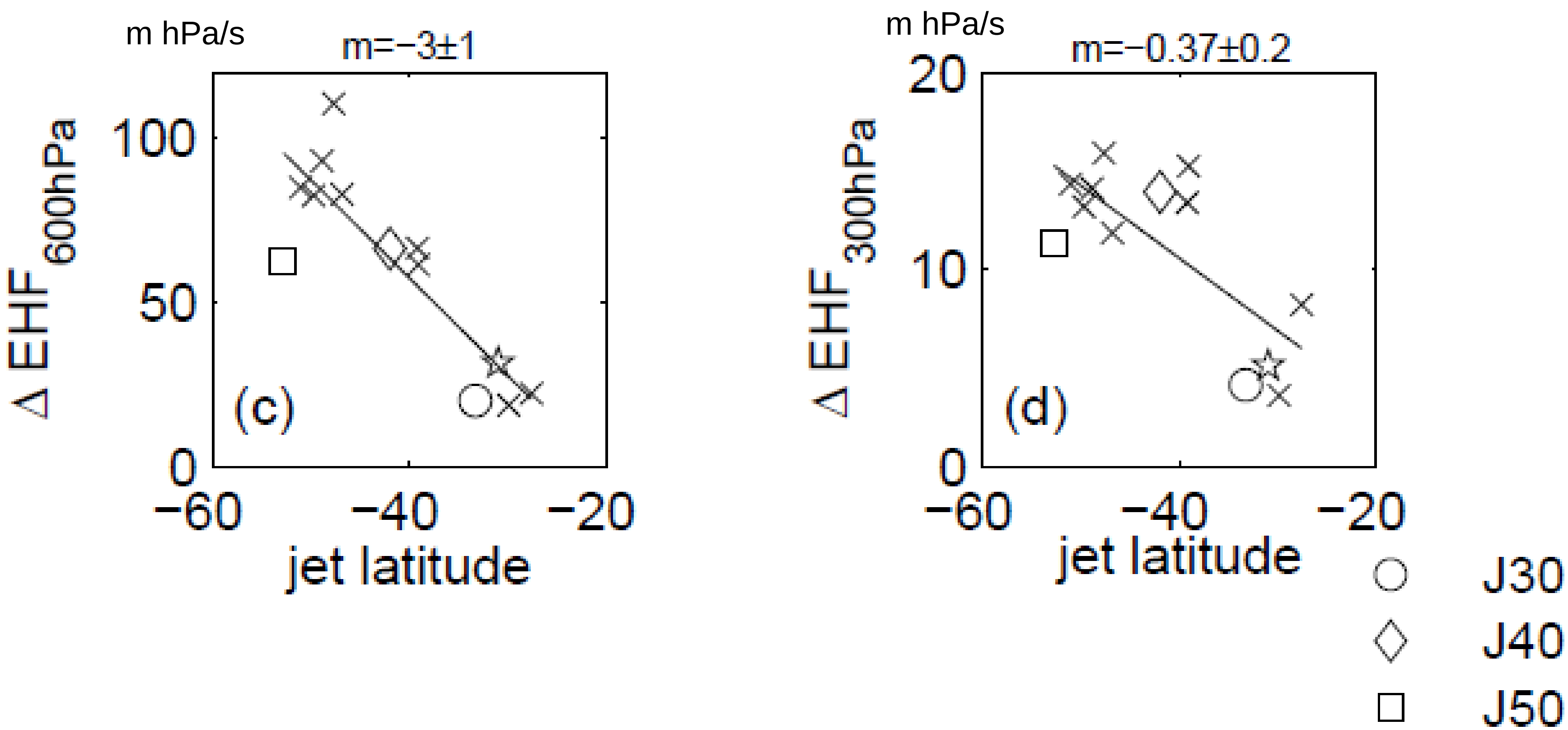
Eddy Fluxes Associated with Jet Shift



Changes in eddy heat flux can not explain the magnitude of jet shift.

Unsuccessful Explanation for Magnitude of Shift (4)

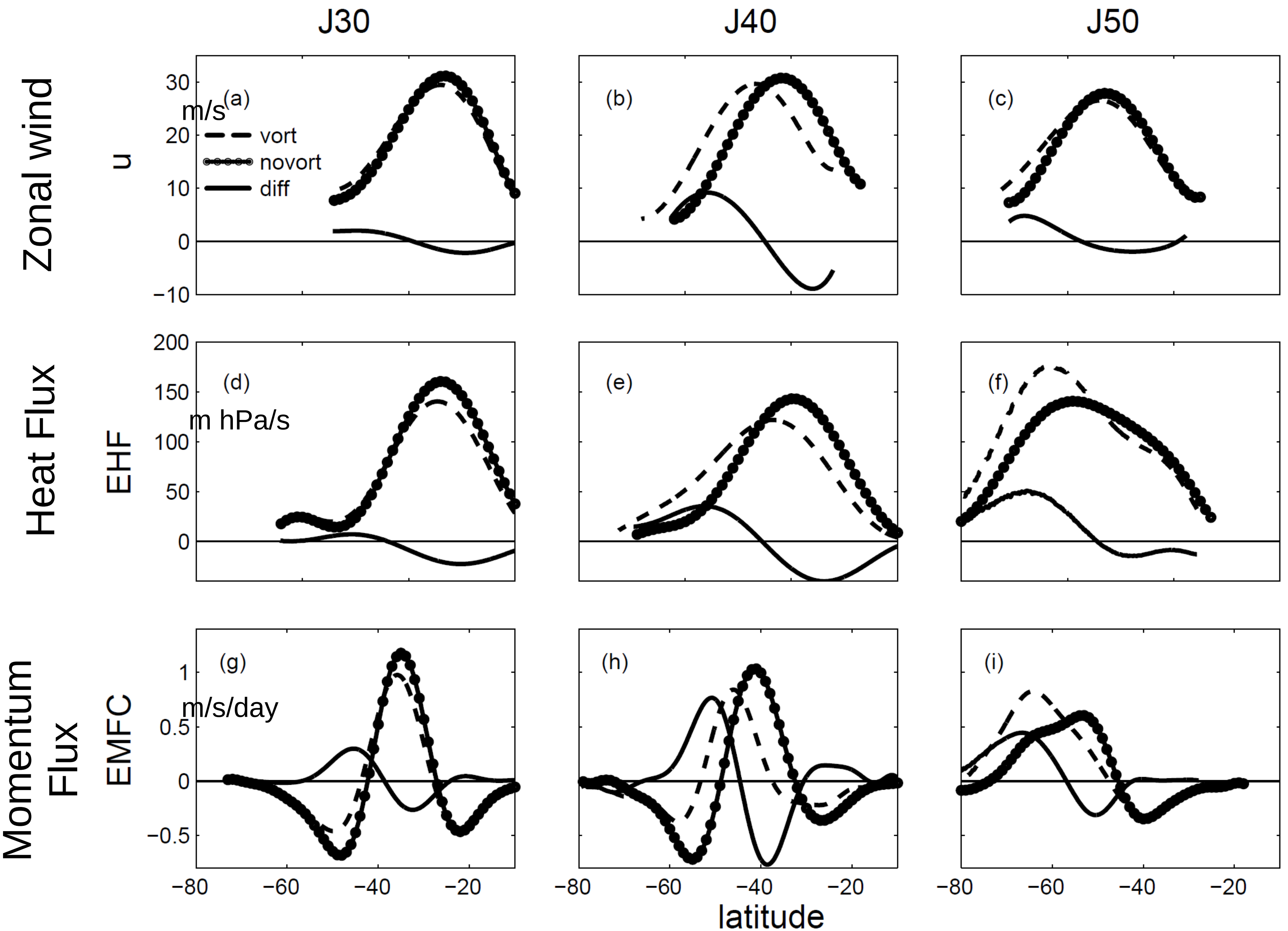


Changes in heat flux can’t explain weaker shift for J50.

Possible Explanations for Magnitude of Jet Shift

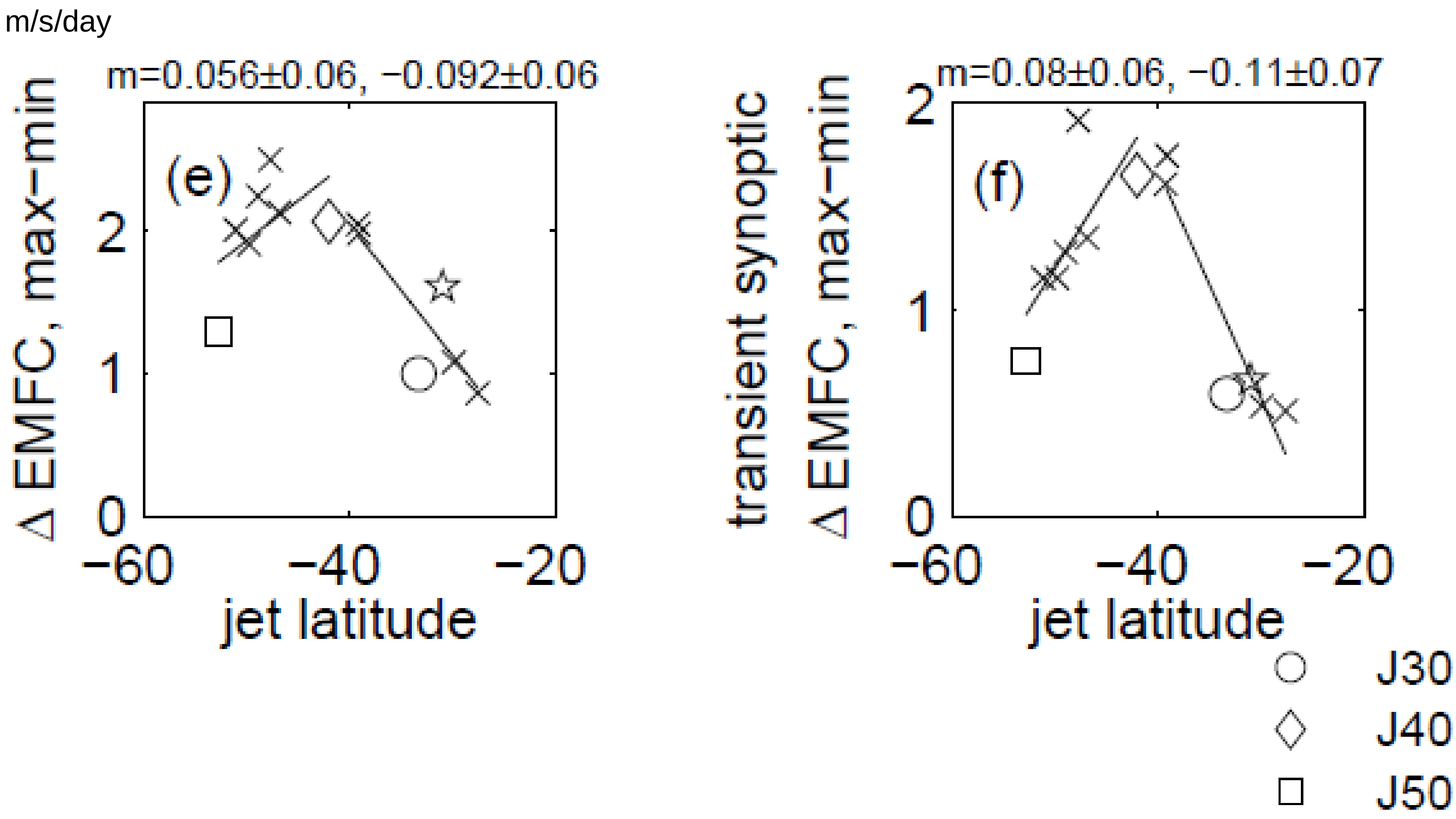
- ~~External forcing associated with vortex projects most strongly onto J40.~~
- ~~Jet variability associated with J40 leads to a stronger response:~~
    - ~~Eddy heat flux~~
    - ~~Eddy length scale~~
    - ~~Eddy phase speed~~
    - ~~PV inversion~~
    - Eddy Momentum Flux
    - Eddy feedback strength of the eddy driven jet

Eddy Fluxes Associated with Jet Shift



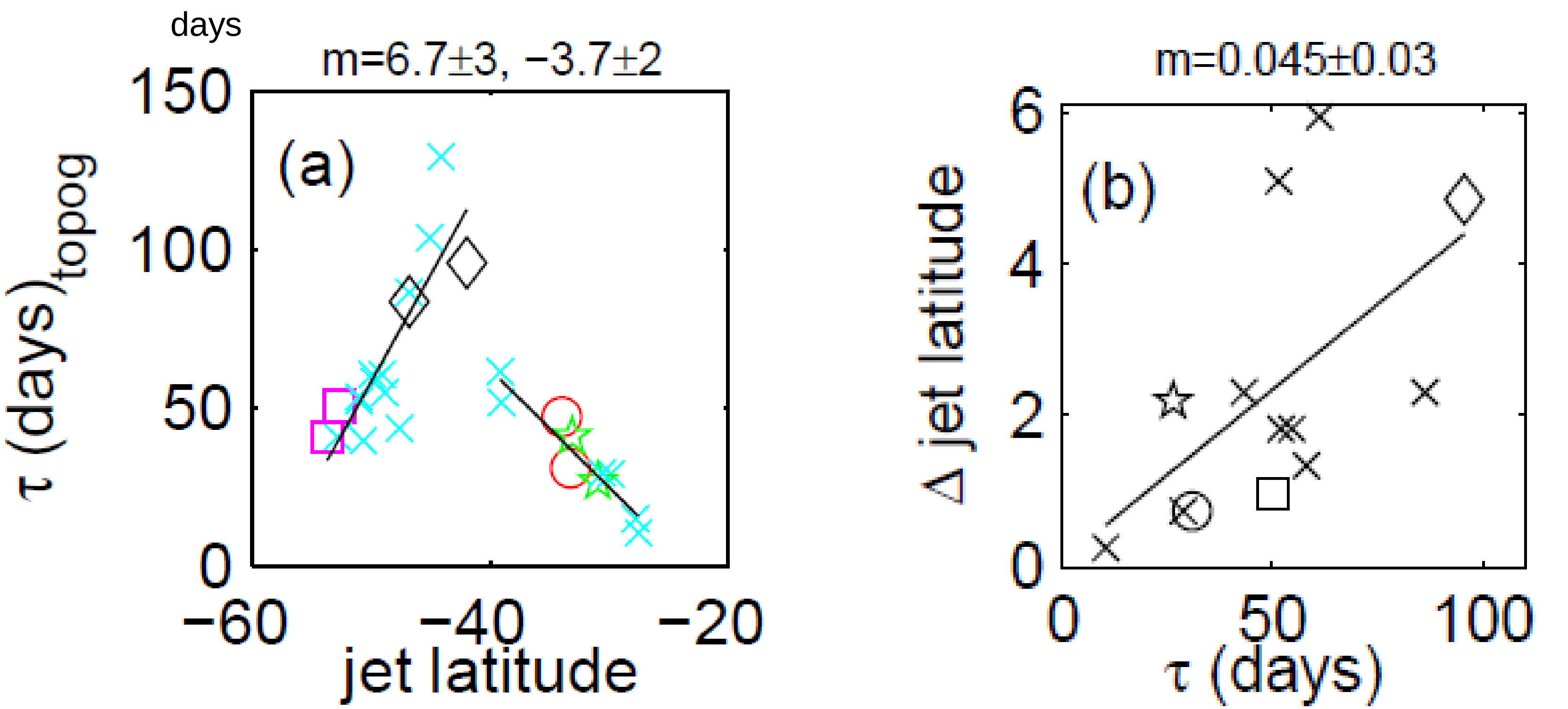
Changes in eddy momentum flux convergence, though not eddy heat flux, can explain magnitude of shift.

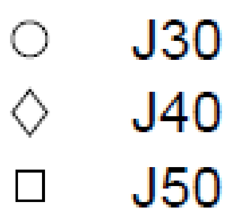
Reponse of Eddies to Vortex



Changes in eddy momentum flux convergence can explain this effect.

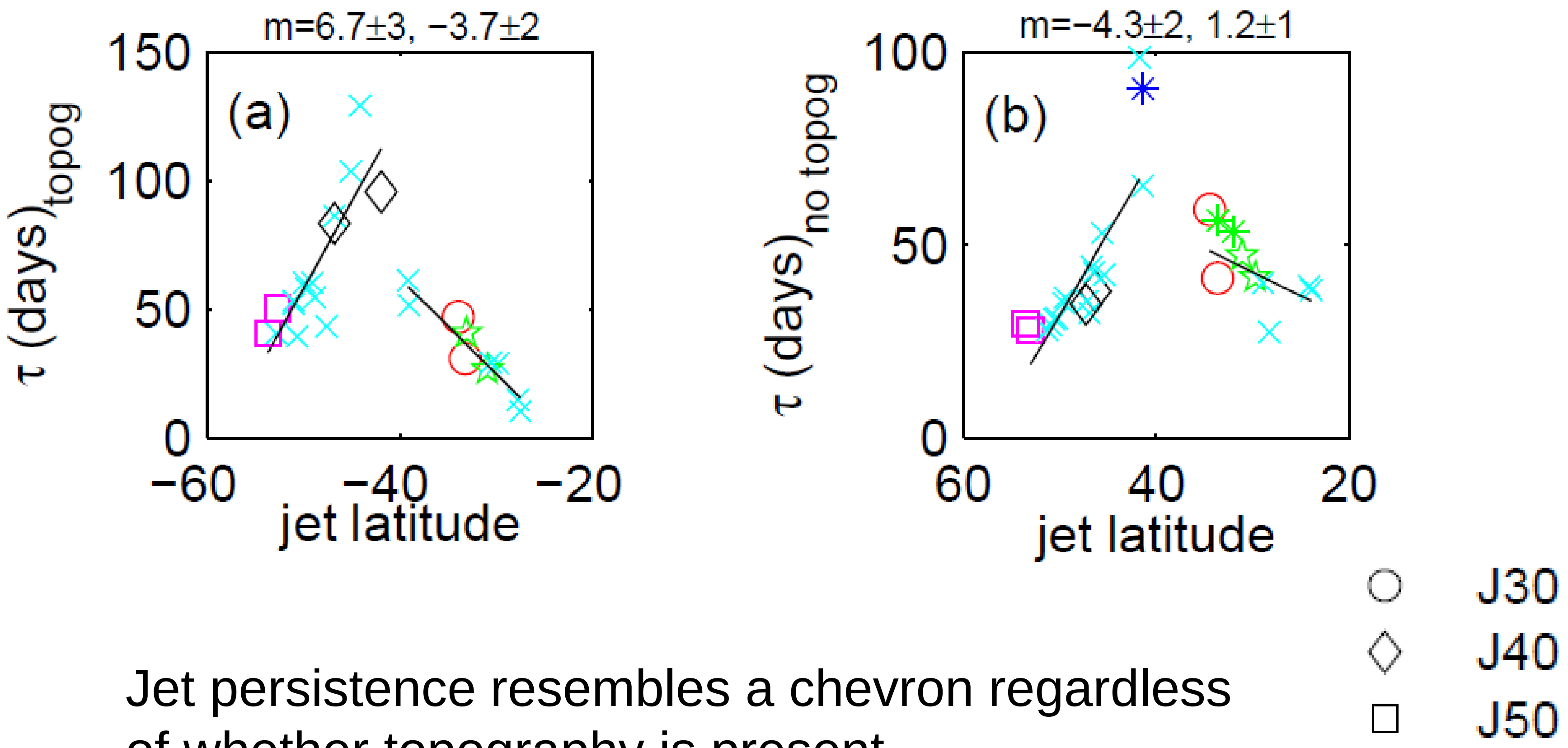
Annular Mode Persistence Timescale





Annular mode persistence resembles a chevron. What about if we have no topography? Can we see this in a more kinematical diagnostic of jet persistence?

Annular Mode Persistence Timescale



Jet persistence resembles a chevron regardless of whether topography is present.

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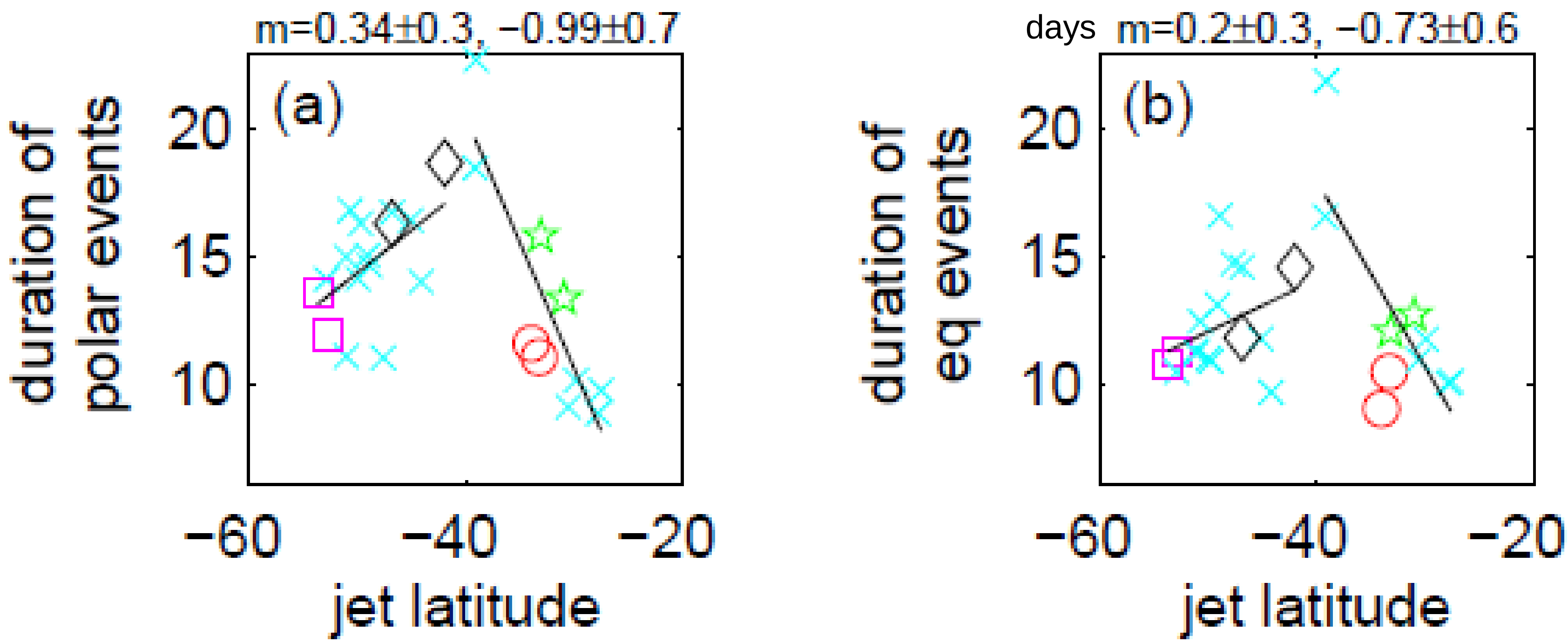
Annular Mode Persistence Timescale



○ J30
◇ J40
□ J50

Jet persistence resembles a chevron even if we use a kinematic metric. Why does the annular mode distribution resemble a chevron?

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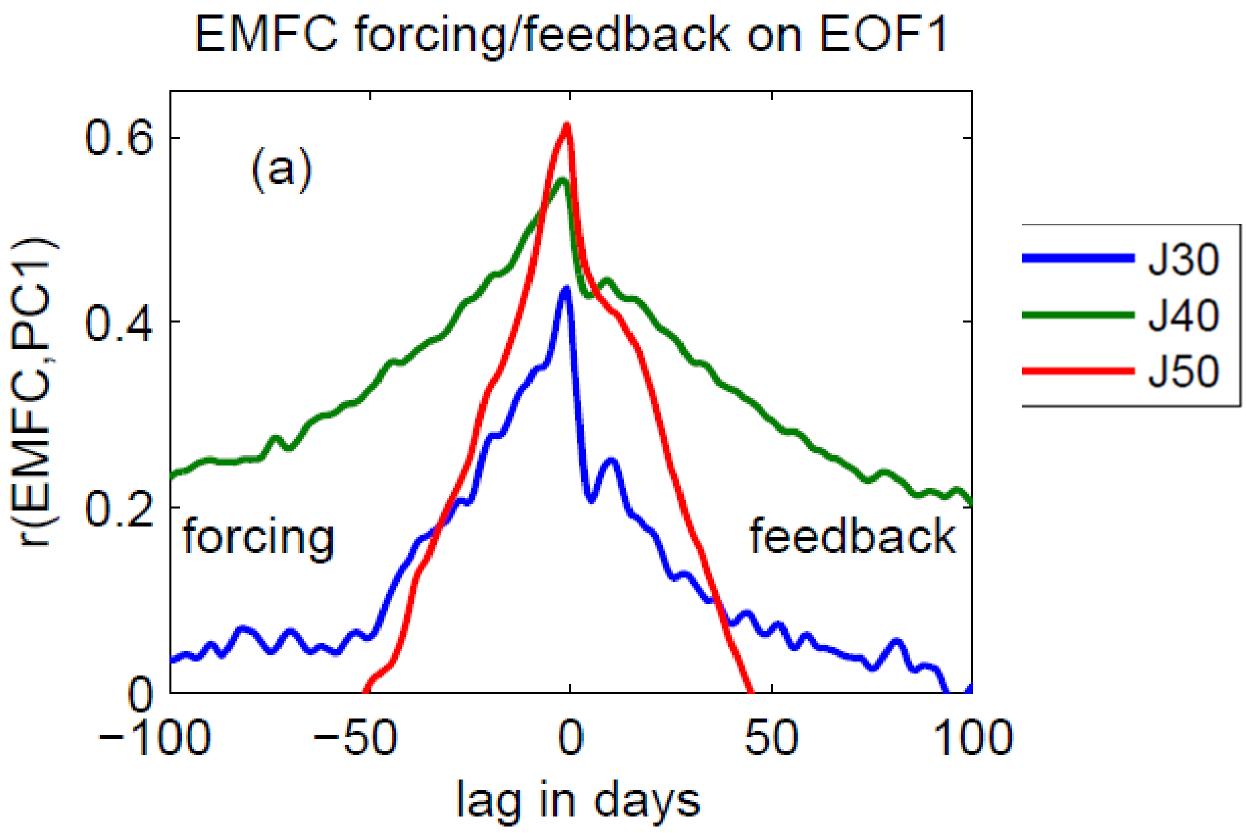
Understanding Variability of the Annular Mode Persistence Timescale

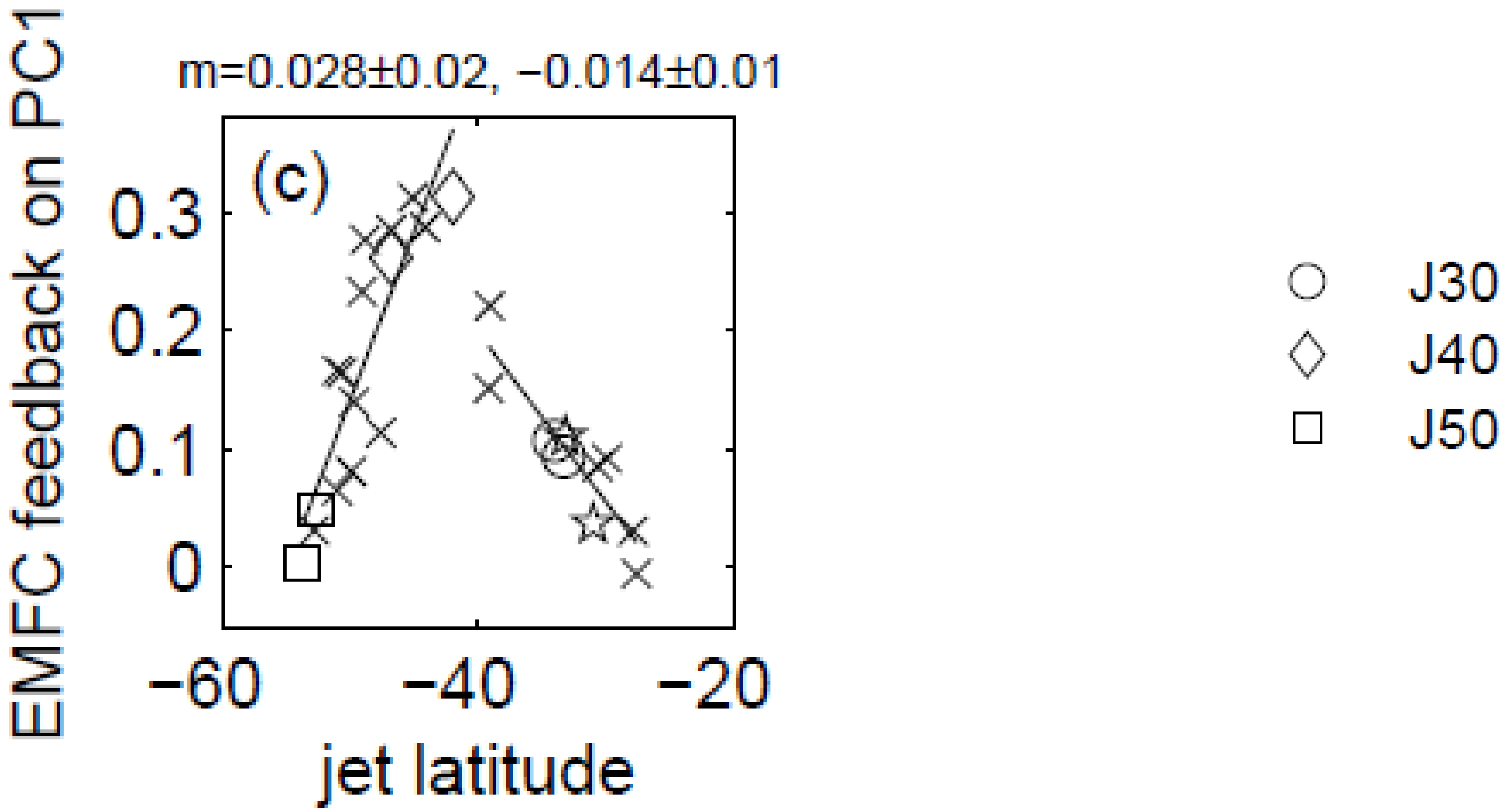


Correlation between projection of high frequency eddy momentum flux convergence onto the annular mode and principal component timeseries of the annular mode

- Eddy feedback on annular mode anomalies is present well after the jet has shifted.
- Eddy feedback is strongest for J40

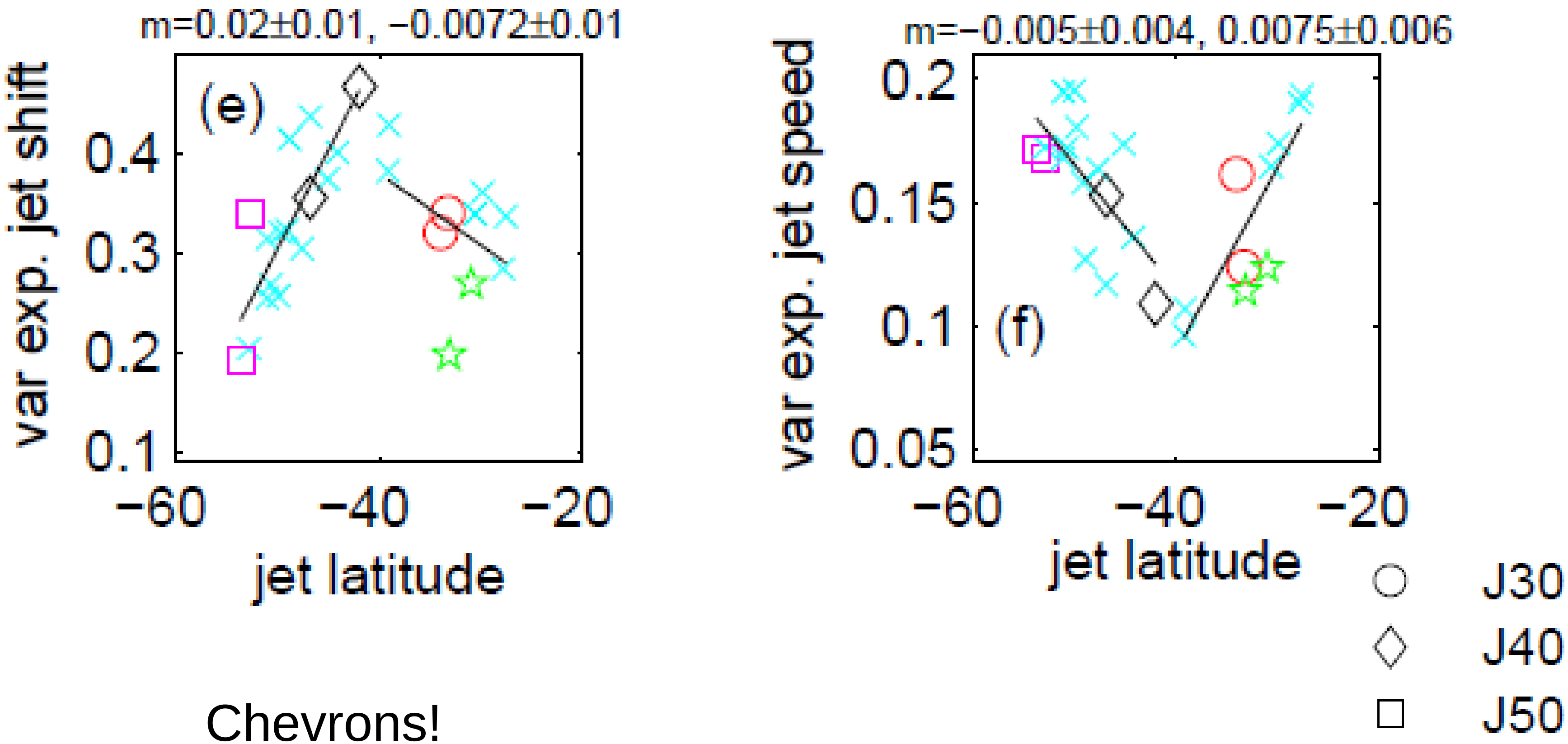
Average of the lagged correlation from 8 days to 88 days

Chevron!



Jets near 30 and 50 have less eddy feedback onto deviations of the annular mode, consistent with the lower annular mode timescales.

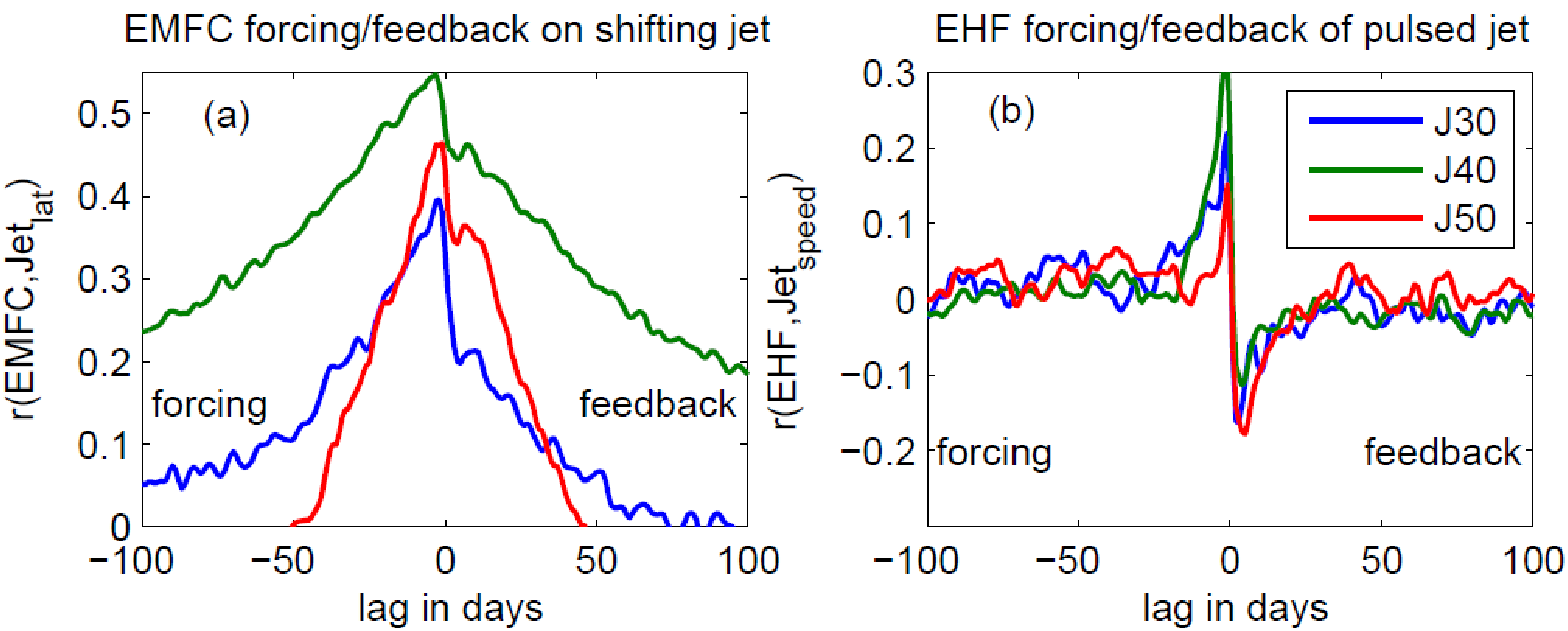
Understanding Variability of the Annular Mode Persistence Timescale



Chevrons!

Jets near 30 and 50 have more variance associated with pulsing and less with shifting, and prior work (e.g. Lorenz and Hartmann 2001) has linked pulsing with weaker eddy feedback and shifting with stronger eddy feedback.

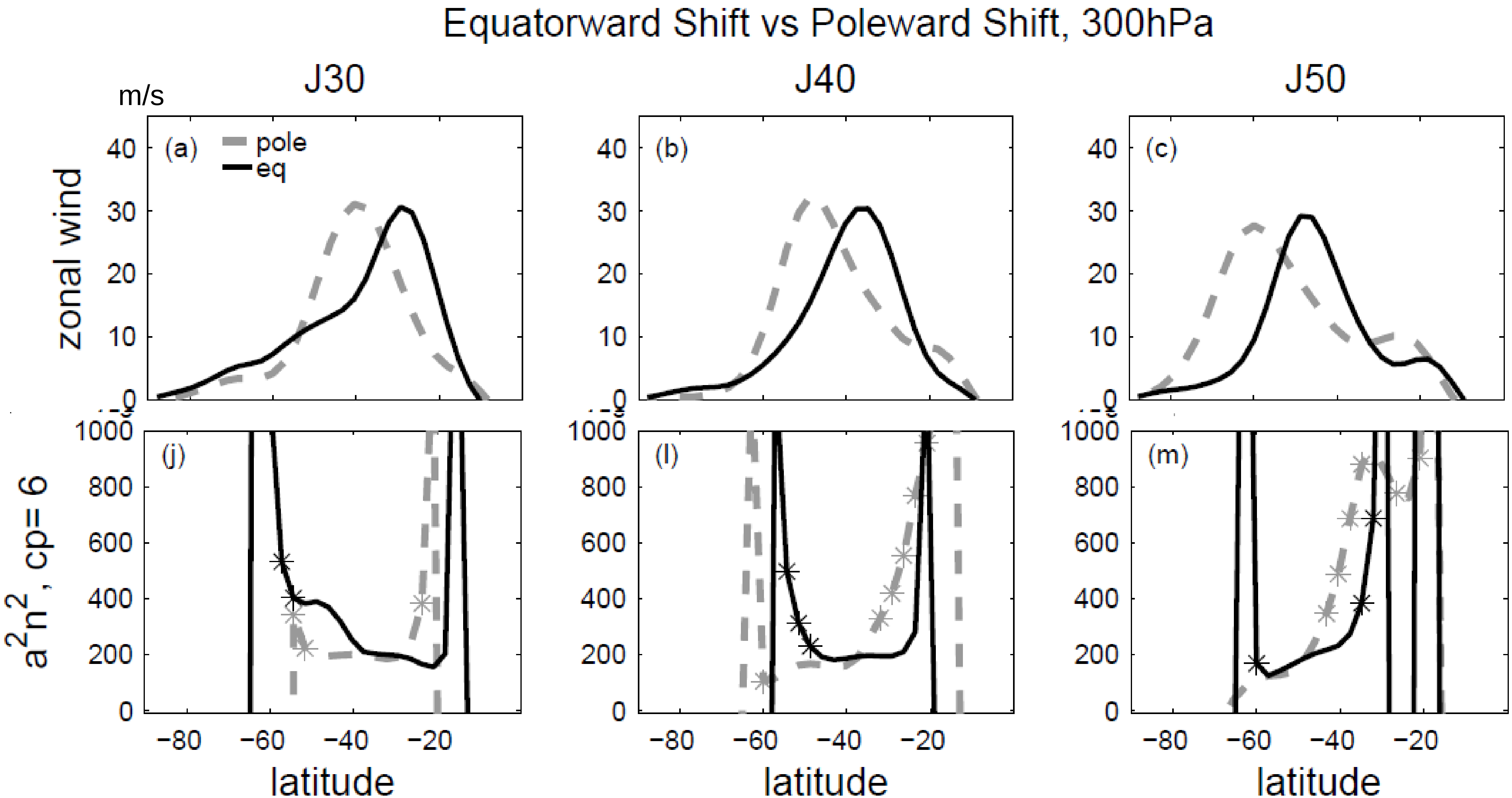
Understanding Variability of the Annular Mode Persistence Timescale



Correlation between projection of high frequency eddy momentum flux convergence onto jet latitude and jet latitude

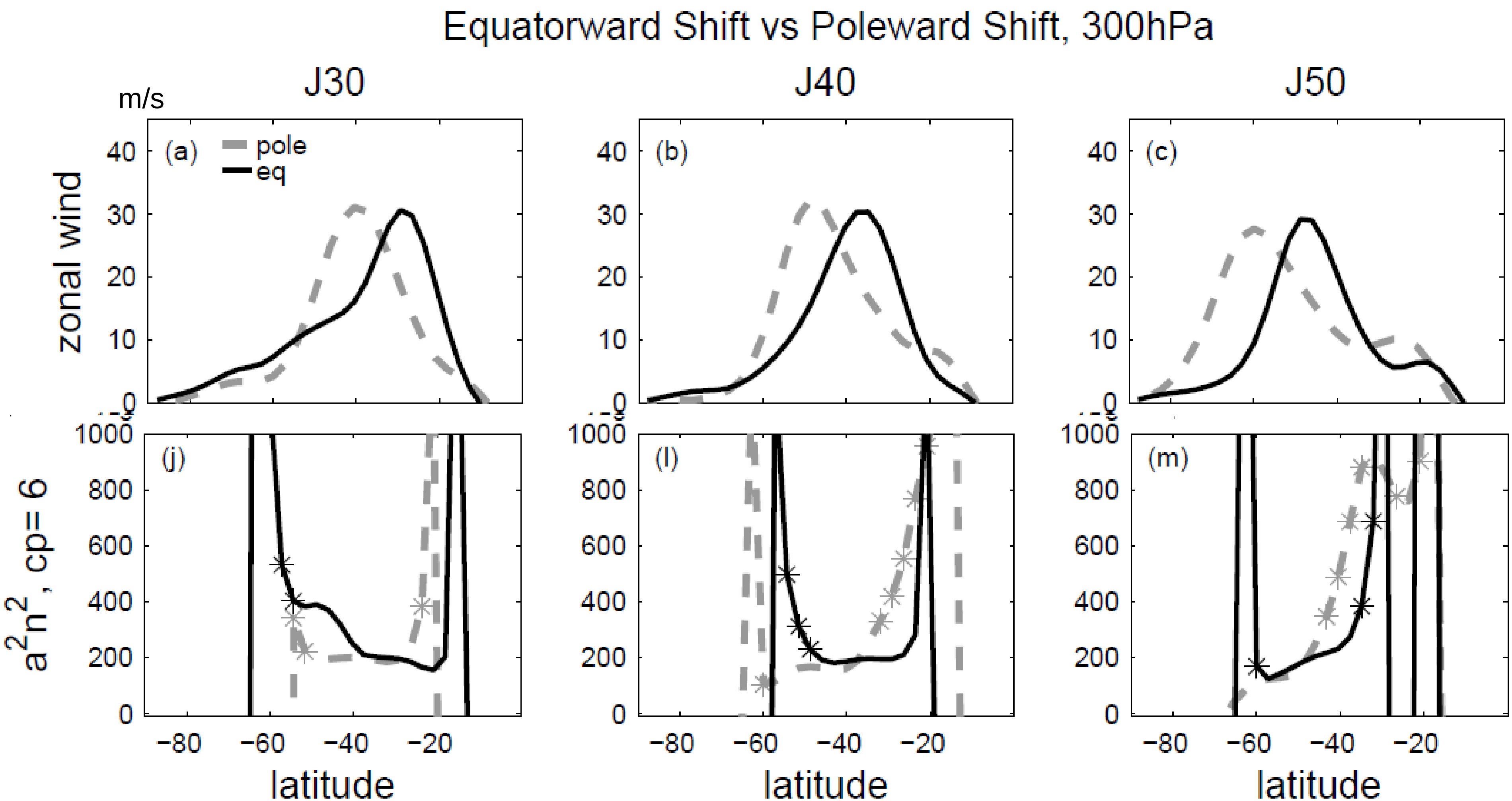
- Eddy feedback is ***negative*** for pulsing of the jet, not positive as for shifting of the jet.

Linear Theory and Persistent Jet Shifts



For higher phase speeds, critical lines shift along with the jet, consistent with previous work.

Linear Theory and Persistent Jet Shifts



For higher phase speeds, critical lines shift along with the jet, consistent with previous work.

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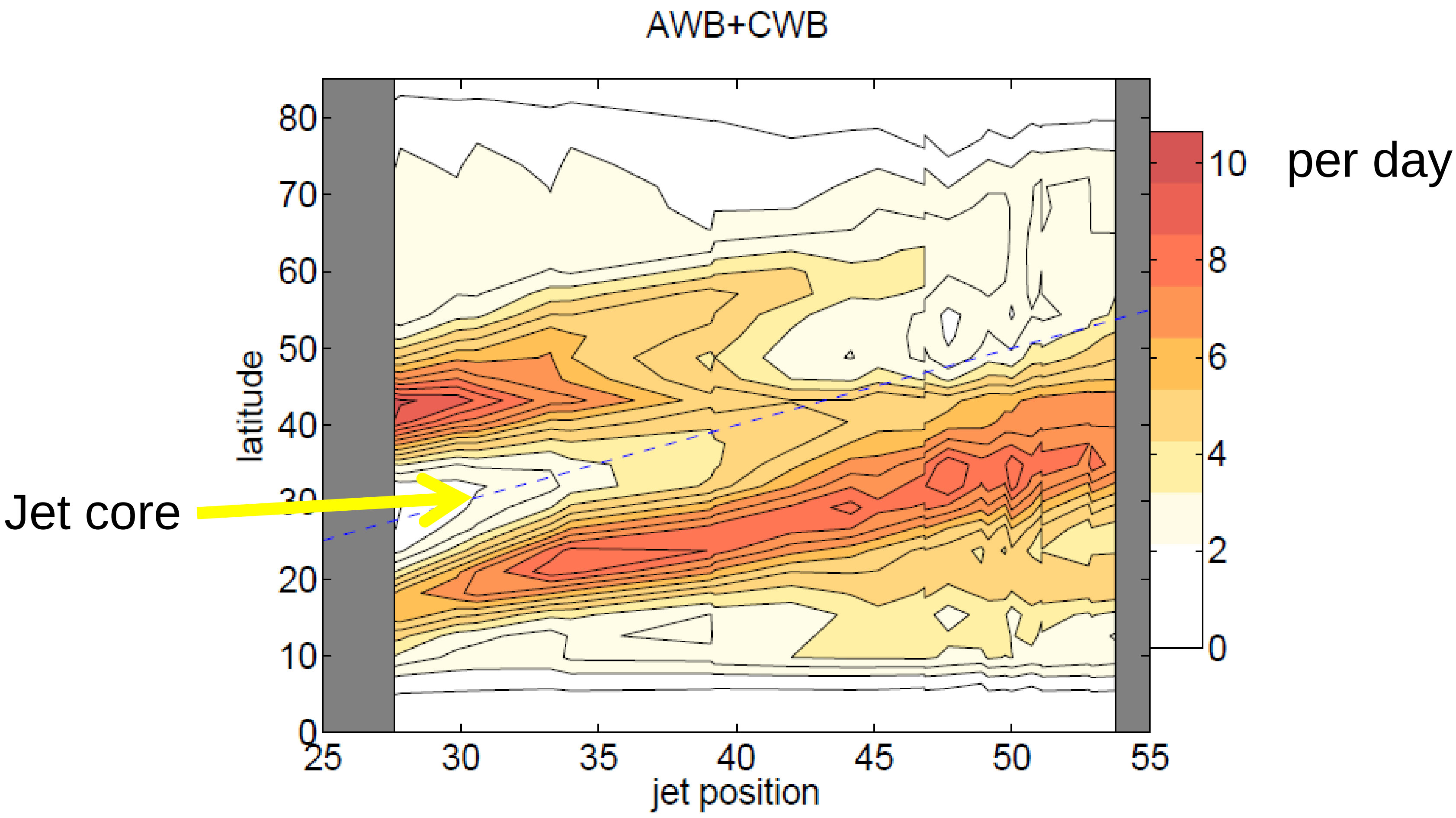
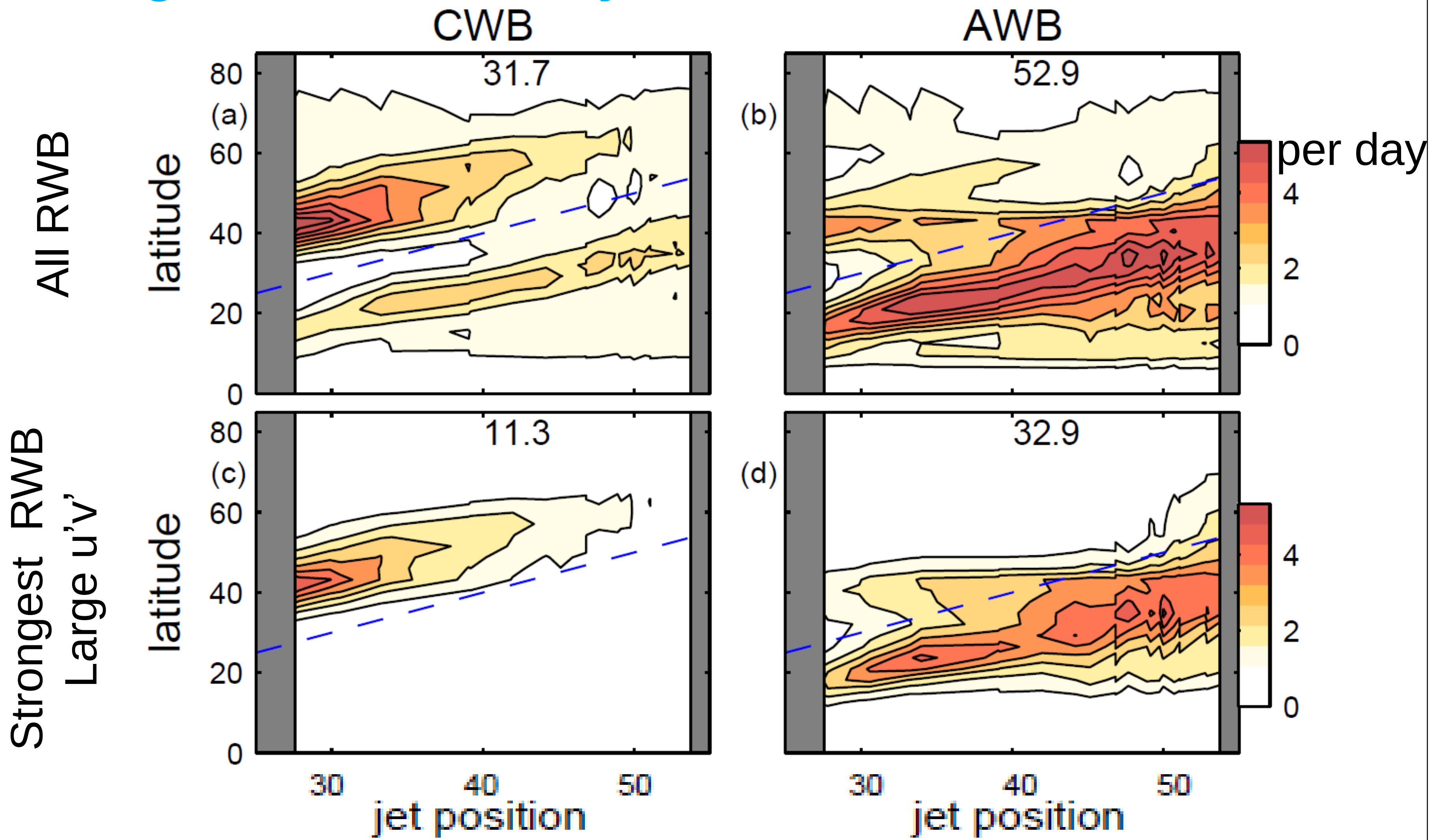
Changes in RWB with jet latitude



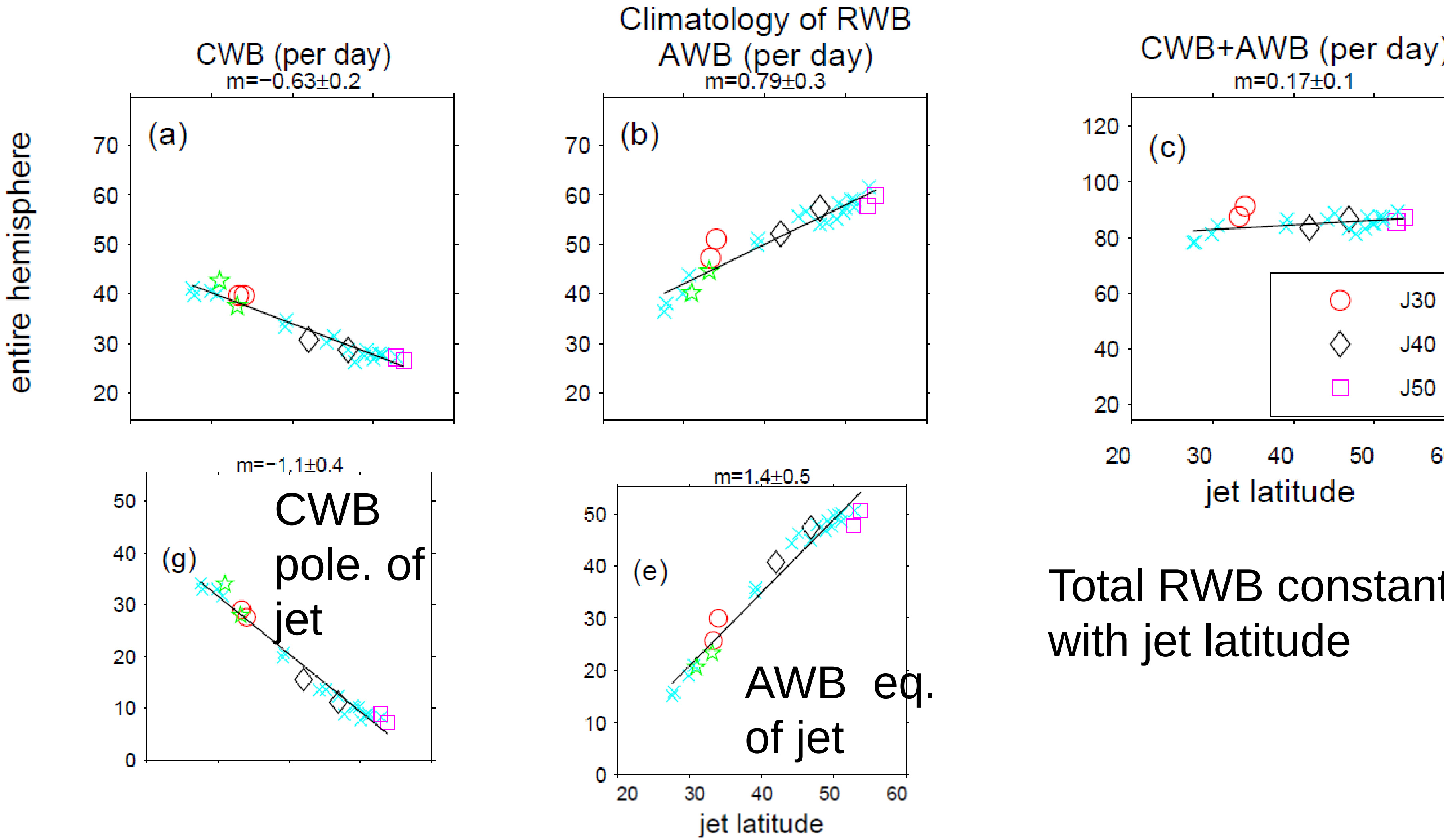
- Relative minima in RWB at the jet core
- RWB frequency on the poleward flank decreases with jet latitude.
- RWB freq. on the equatorward flank has a more complex structure

Changes in RWB with jet latitude



- Most CWB occurs on poleward flank, while most AWB occurs on equatorward flank
- This tendency is even stronger if we focus on the strongest 30% of the events

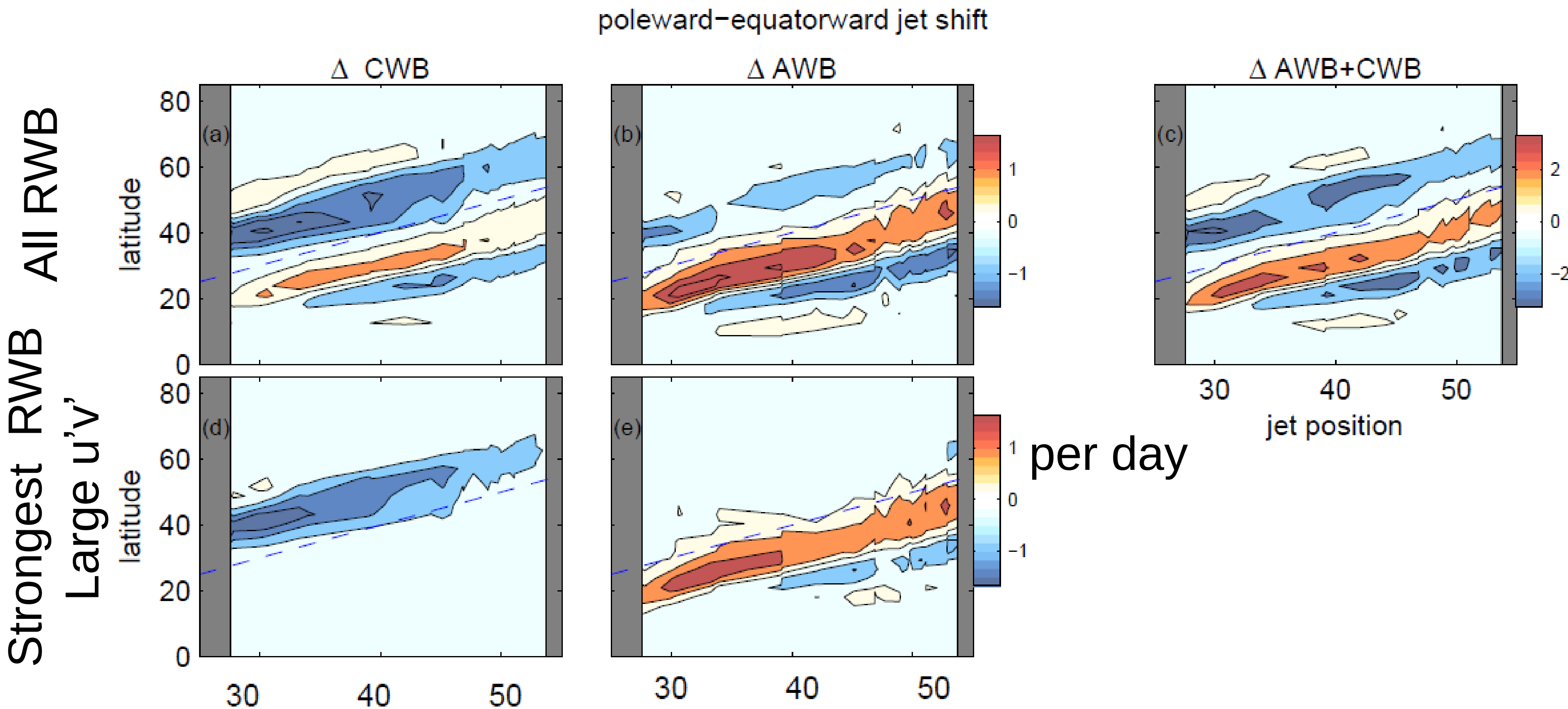
Changes in RWB with jet latitude



Total RWB constant with jet latitude

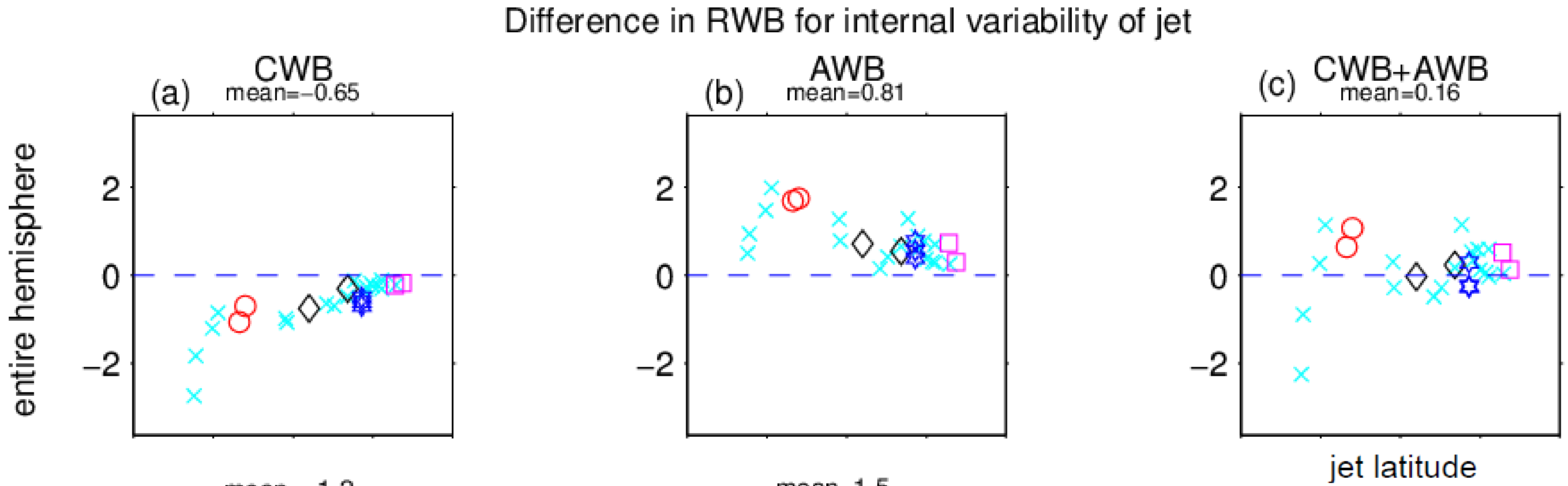
- CWB decreases as the jet moves polewards, while AWB frequency increases as the jet moves polewards
- This effect is dominated by CWB on the poleward flank and AWB on the equatorward flank

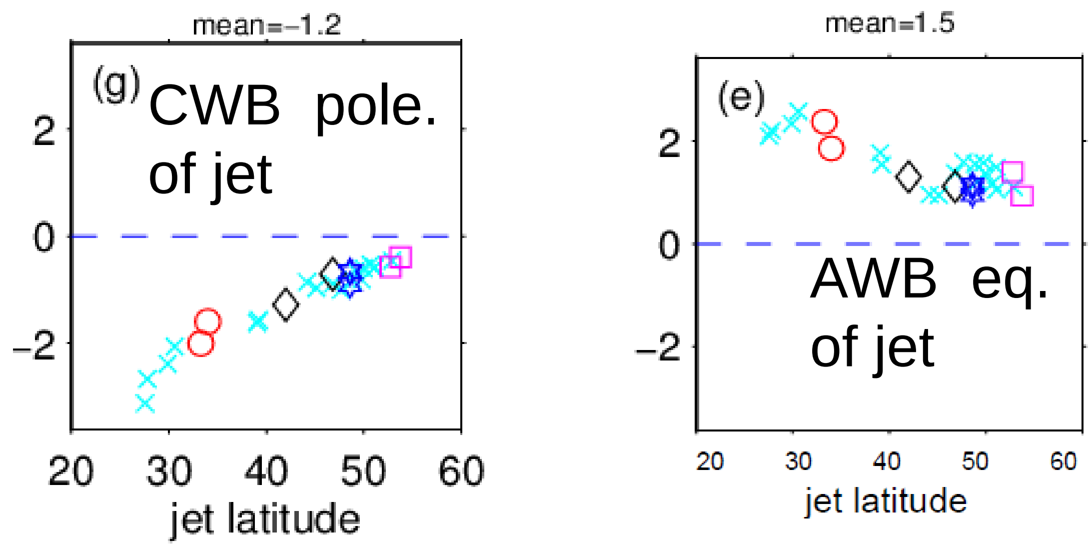
Response of RWB to internal variability



- CWB decreases as the jet moves polewards, while AWB frequency increases as the jet moves polewards
- This effect is dominated by CWB on the poleward flank and AWB on the equatorward flank

Changes in RWB per degree jet shift ($\Delta RWB/\Delta lat$)



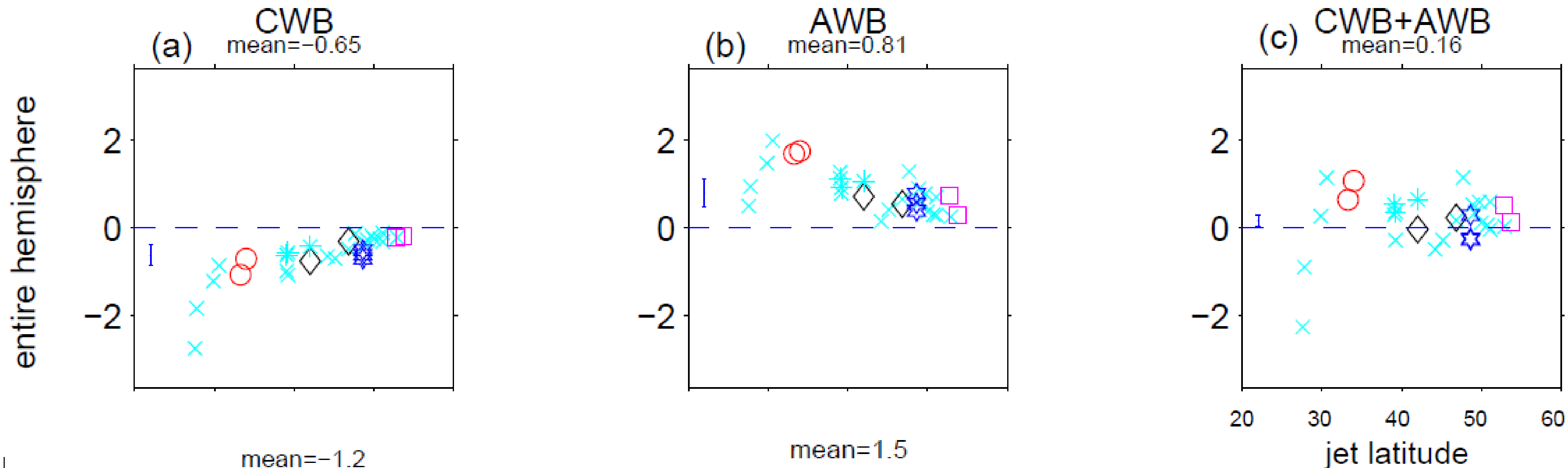


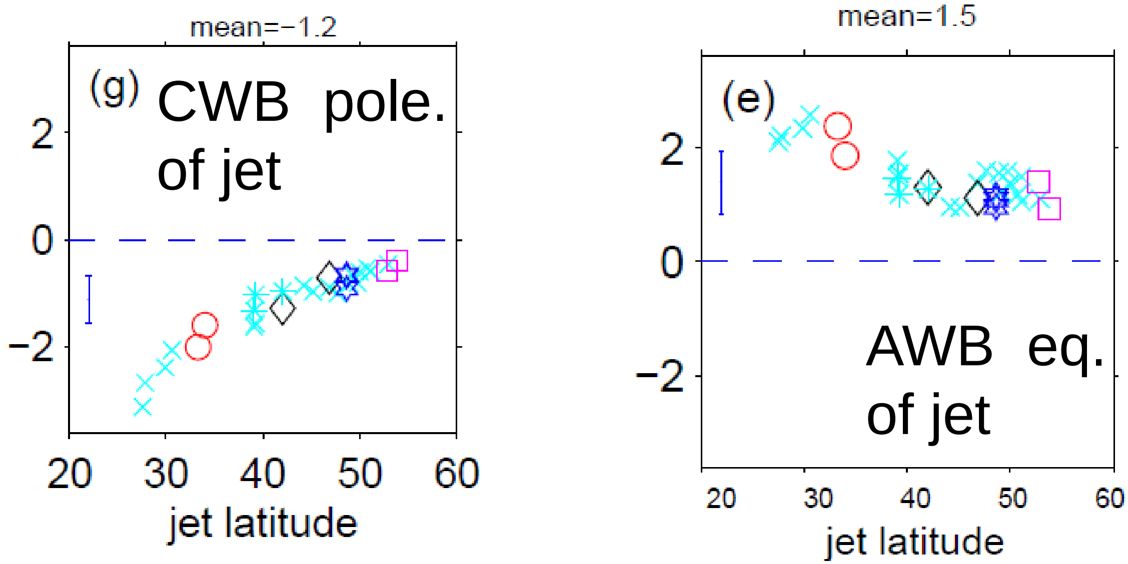
Blue stars: change in RWB associated with internal variability in MERRA

all other markers: change in RWB associated with internal variability in dry model

- Change in RWB per degree jet shift associated with internal variability is indistinguishable between MERRA and the dry model.

Changes in RWB per degree jet shift ($\Delta RWB/\Delta lat$)





Error bar: change in RWB associated with climatological jet position
Asterisk: change in RWB associated with polar vortex
Blue stars: change in RWB associated with internal variability in MERRA

- Change in RWB per degree jet shift associated with any forcing is identical.
- RWB likely cannot be used to isolate the causality of a jet shift.

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Conclusions

•The effect of a polar vortex on the troposphere is largest for a jet near 40. This is consistent with (1) the observed larger effect in the North Atlantic than in the North Pacific, and (2) studies on the SH response to ozone and carbon dioxide changes.

•Jet variability associated with J40 leads to a stronger response:

- More persistent jet
- ~~Eddy Length Scale~~
- ~~Eddy Phase speed~~
- Eddy Momentum Flux
- ~~Eddy Heat Flux~~

Garfinkel, C. I., D. W. Waugh, E. P. Gerber (accepted), The Effect of Tropospheric Jet Latitude on Coupling between the Stratospheric Polar Vortex and the Troposphere, J. Clim., doi: 10.1175/JCLI-D-12-00301.1.

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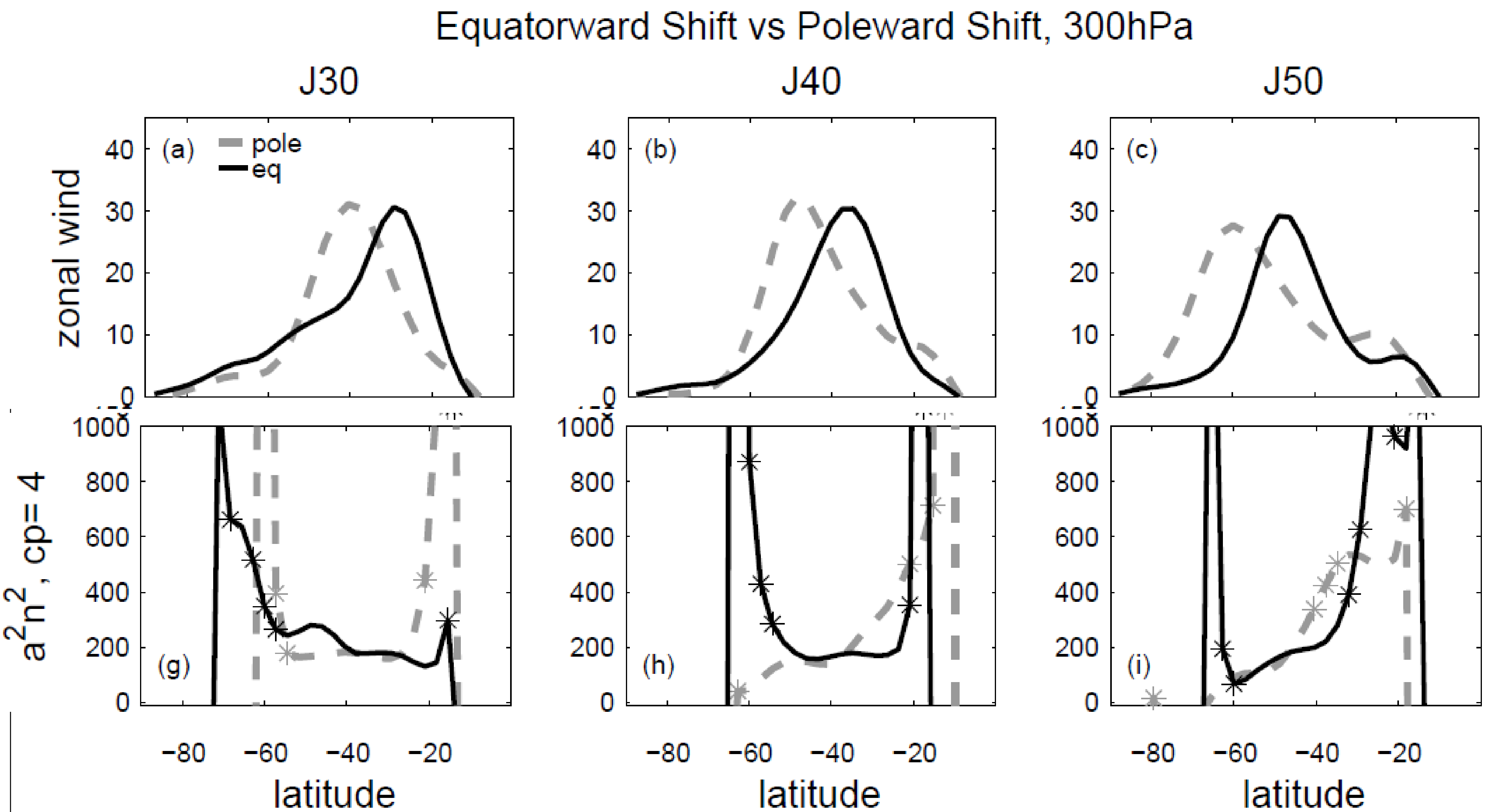
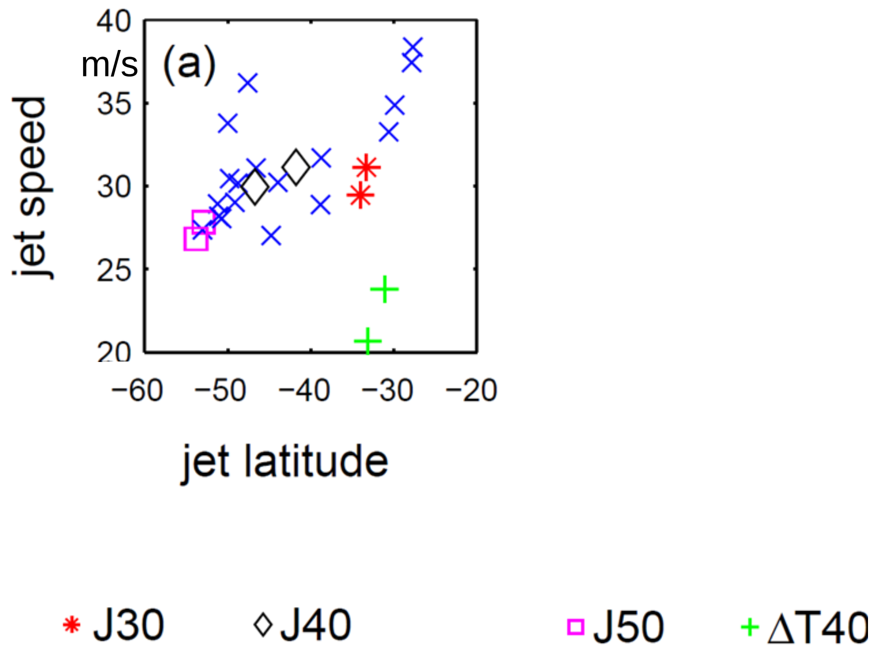
Understanding Variability of the Annular Mode Persistence Timescale



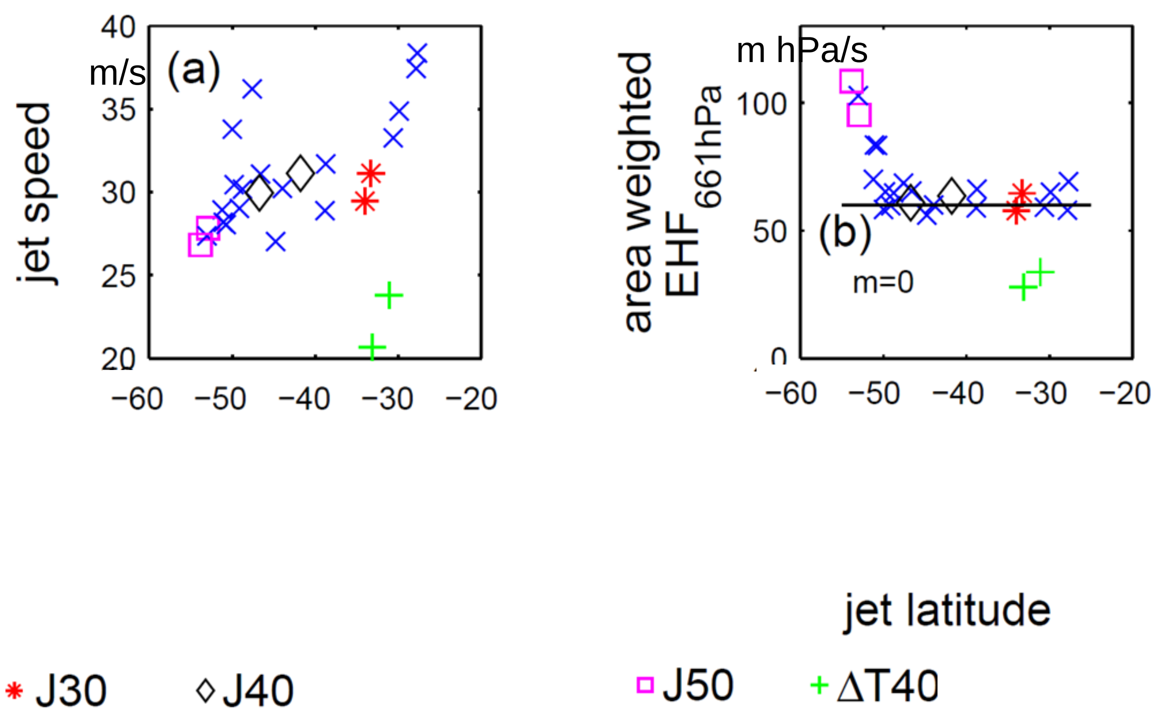
For intermediate phase speeds, critical line arguments begin to fall apart, though they still work for J40. (For lower phase speeds, they don't appear to work for any case- not shown)

Properties of Jets Irrespective of Vortex



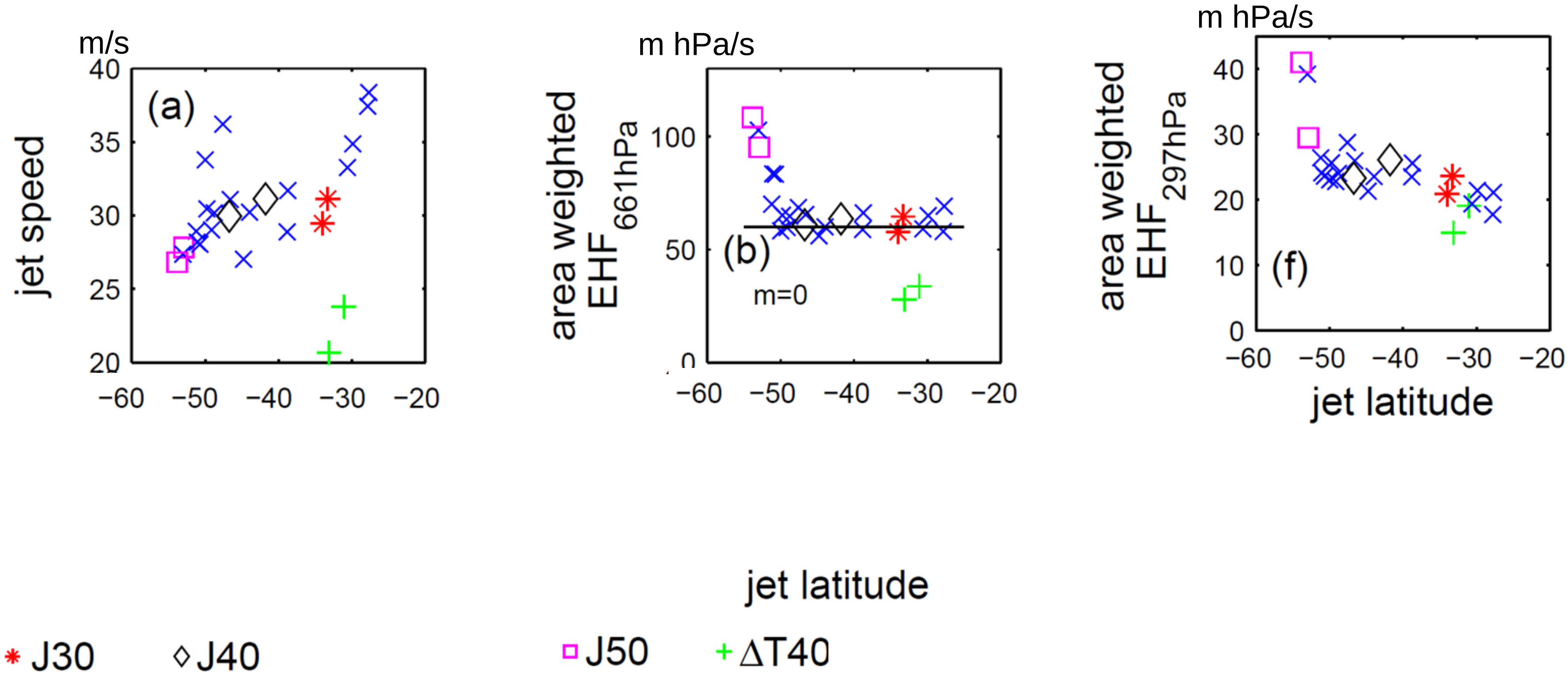
Near constant maximum wind speed

Properties of Jets Irrespective of Vortex



Near constant total eddy northward heat flux

Properties of Jets Irrespective of Vortex



Near constant total eddy northward heat flux at upper levels as well, though a slight tendency towards more for more poleward jets.

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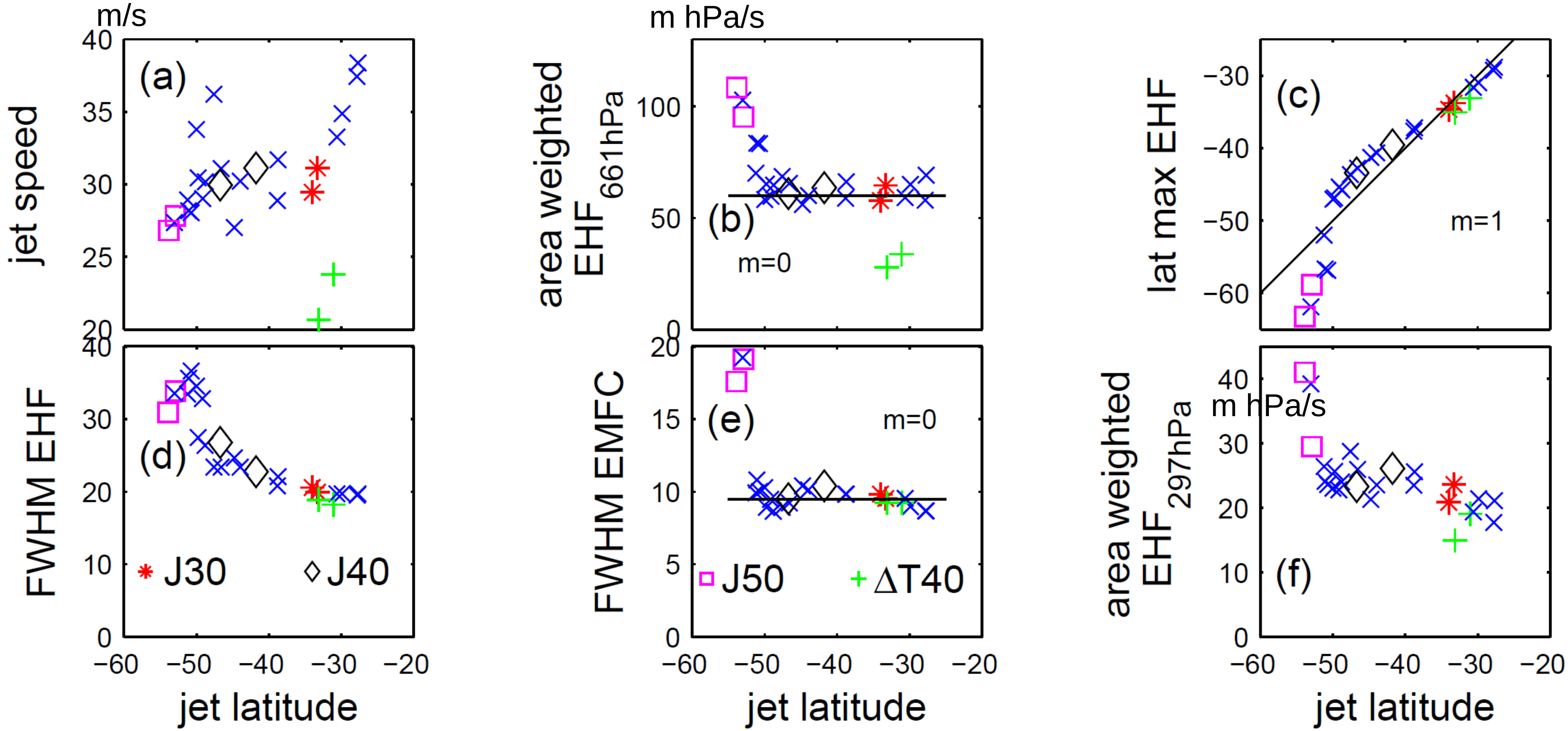
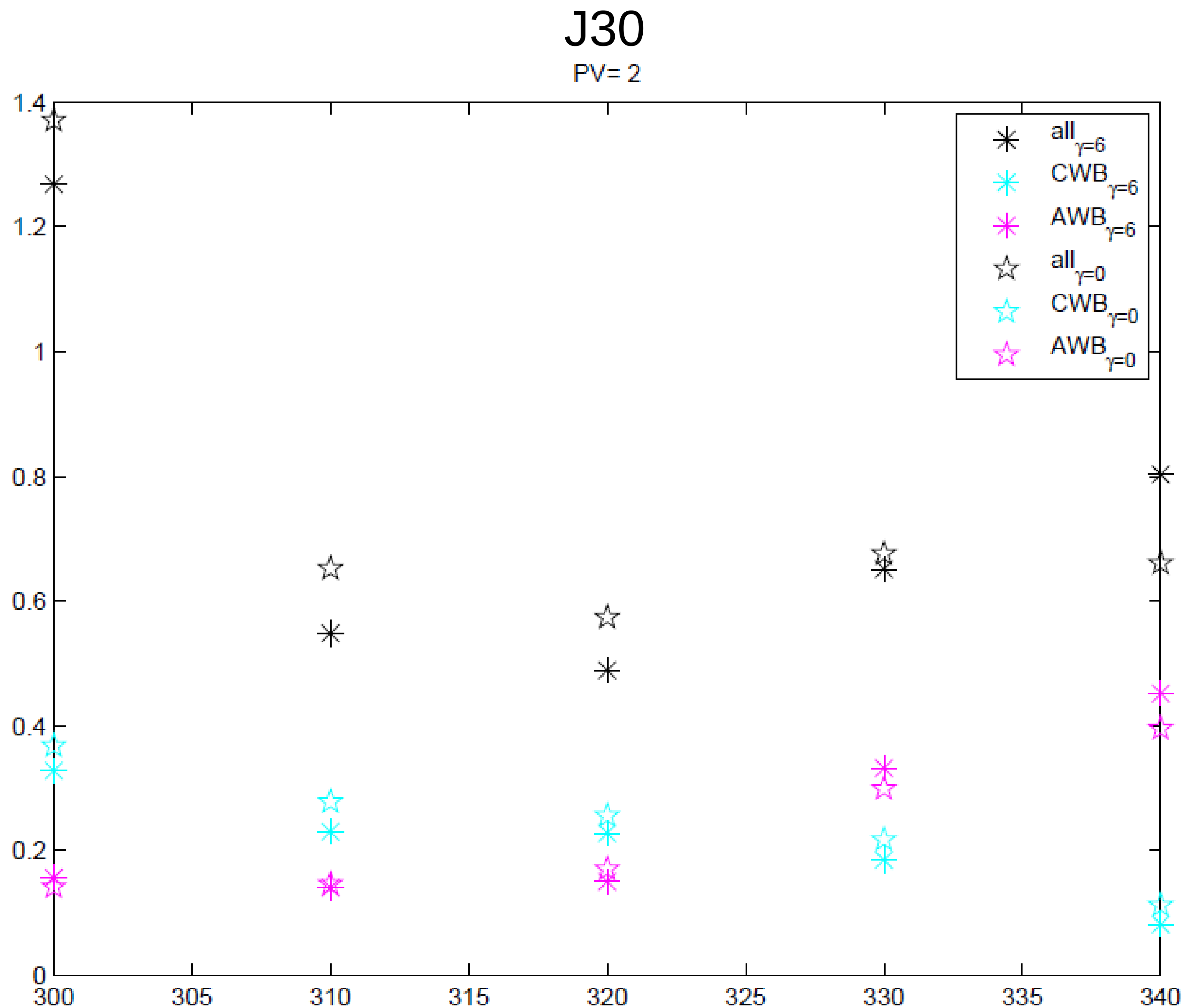
Properties of Jets Irrespective of Vortex



Latitude of maximum heat flux roughly follows jet latitude

Width of heat flux, though not momentum flux, increases with jet latitude

Additional Properties of Control Run Jets



poleward

equatorward

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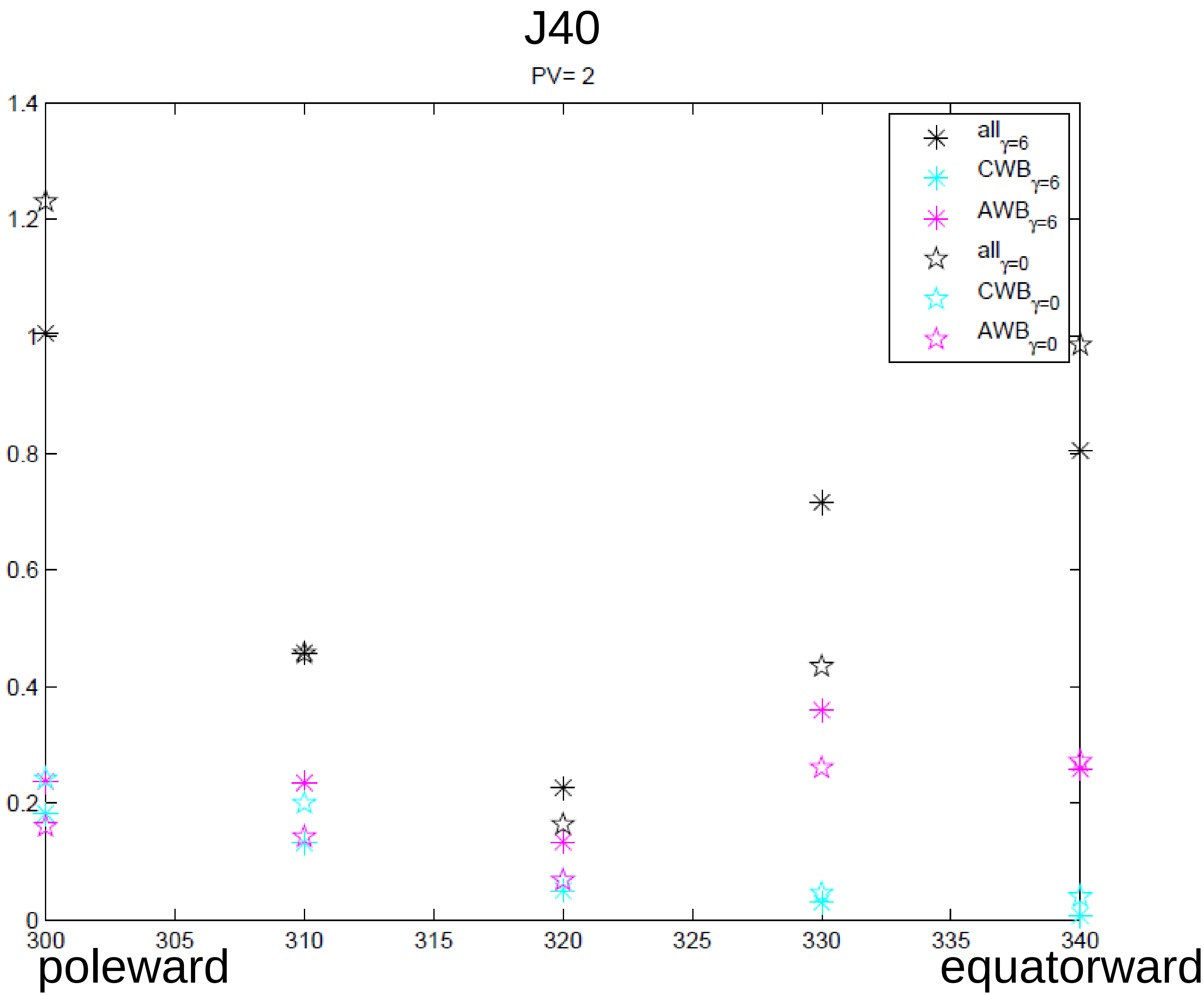
More AWB equatorward of jet core, less CWB poleward of jet core

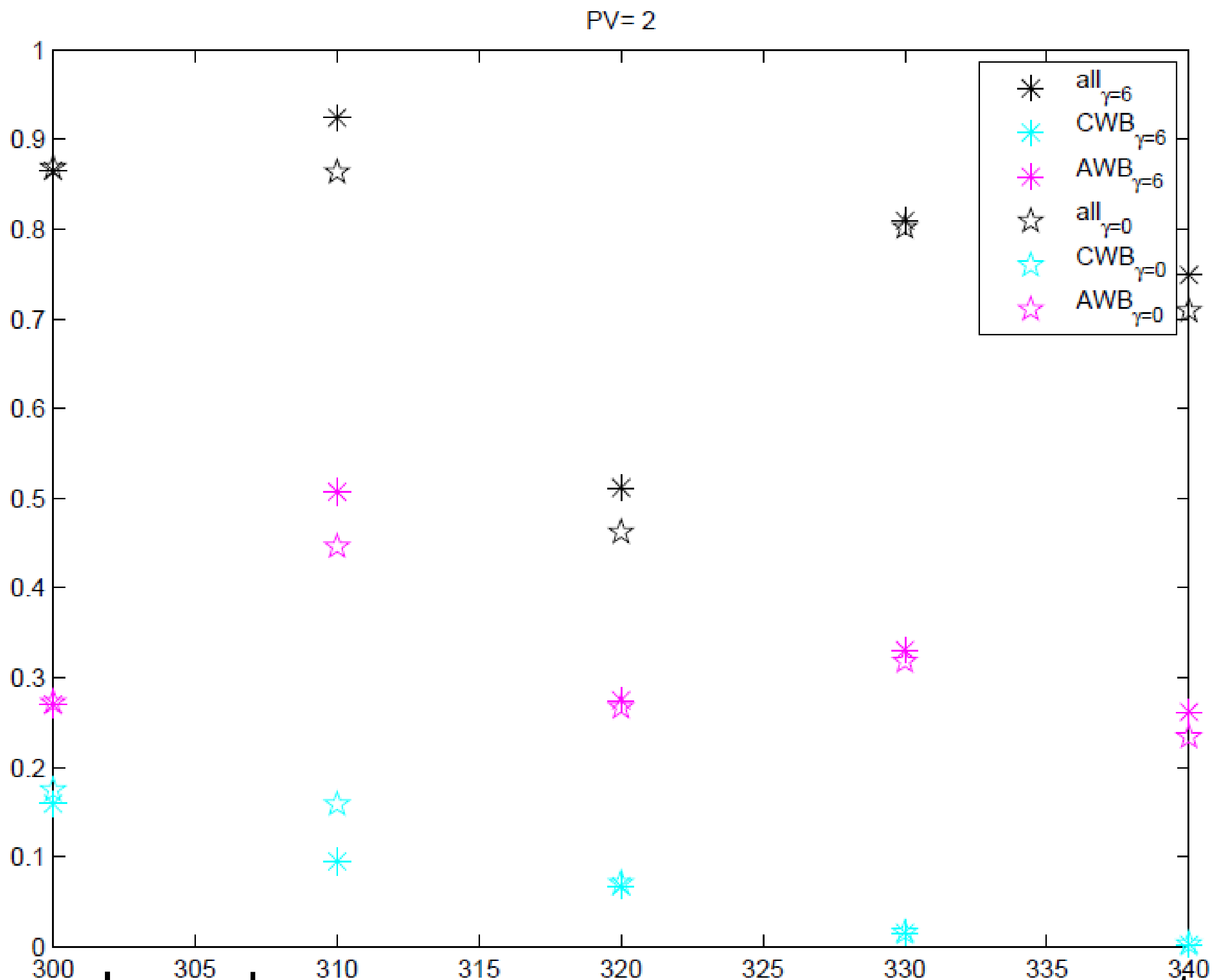
Additional Properties of Control Run Jets



More AWB equatorward of jet core (everywhere actually), less CWB poleward of jet core

Additional Properties of Control Run Jets

J50



poleward equatorward

More AWB equatorward of jet core, less CWB poleward of jet core

Control Run Jets

Place jets at 30, 40, and 50.

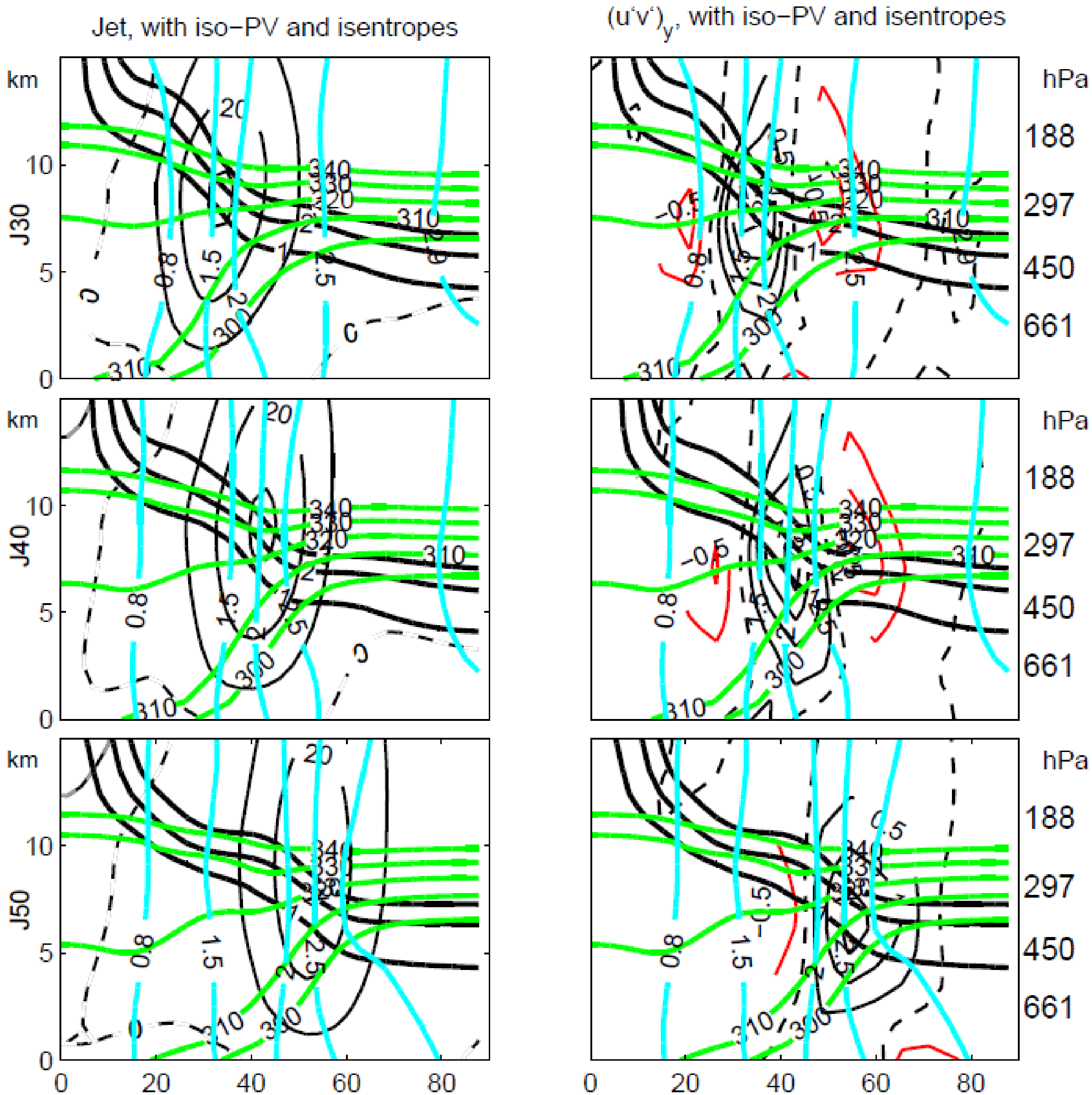


Fig 3:

Ensemble of other Jets

Creat jets with a wide range of jet latitudes.

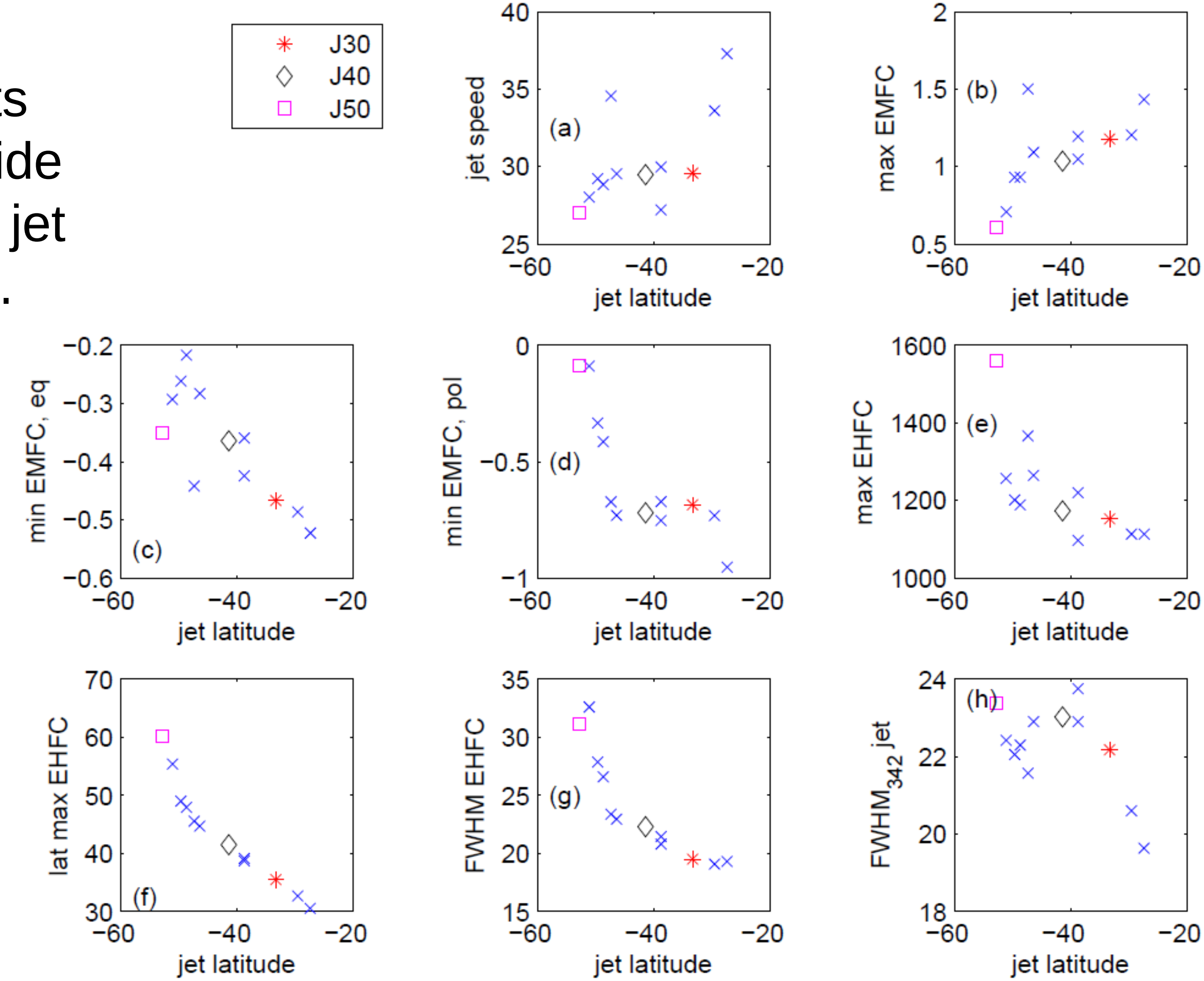


Fig 4:

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Response to Vortex

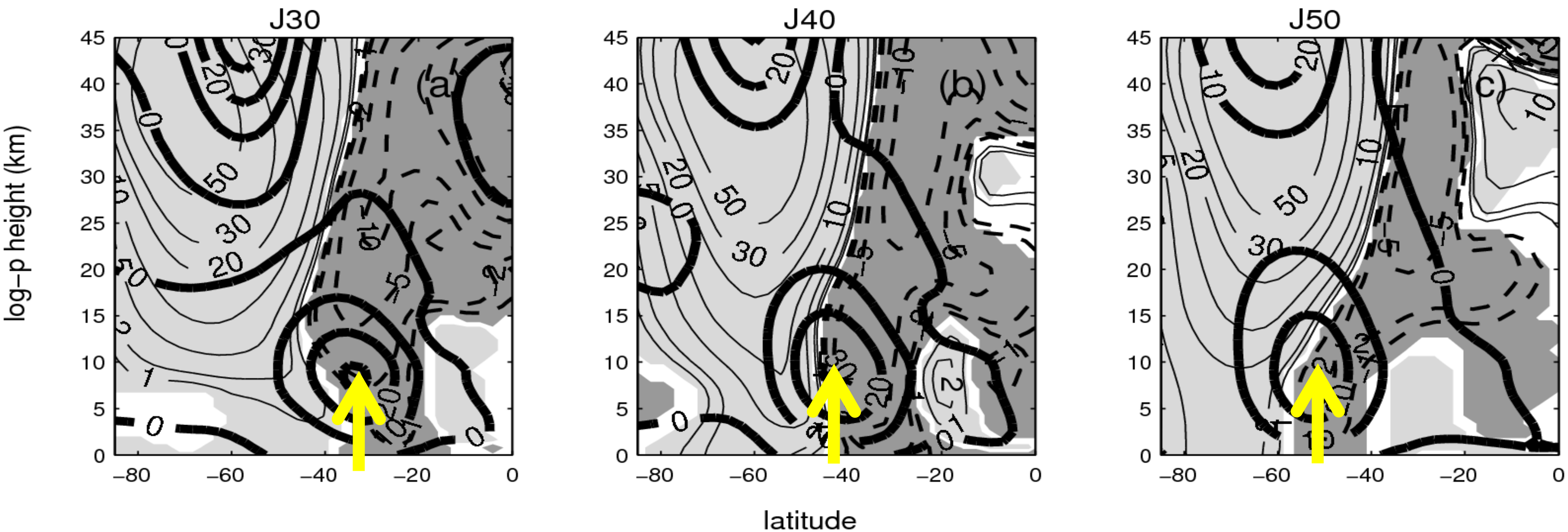

Figure 1con: Time mean zonal mean zonal wind for three jet configurations (bold solid contours, Contour interval 10m/s) and change in zonal mean zonal wind between control integration (γ=0) and integration with a strong polar vortex (γ=6, thin solid and dashed contours).

- Poleward shift in all cases. Weakest shift in J30 and strongest shift in J40.
- Implications for response in NH Pacific and Atlantic sectors to vortex variability.

Response to Vortex, Eddies

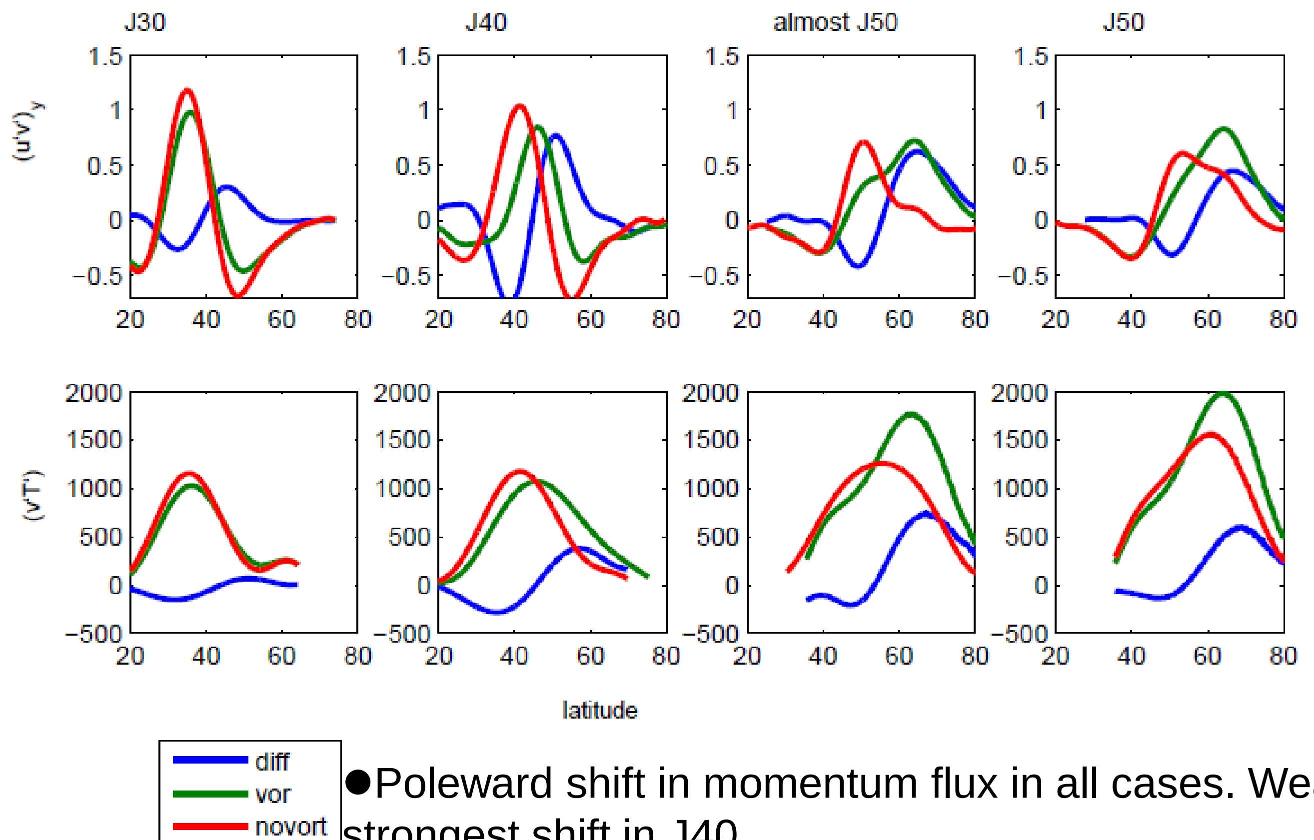

Figure 5: Time mean zonal mean high frequency eddy fluxes. ???

- Poleward shift in momentum flux in all cases. Weakest shift in J30 and strongest shift in J40.
- Heat flux changes as well, but does not explain the response.
- Why do eddies react so strongly in the J40 case?

Axisymmetric circulation associated with the vortex

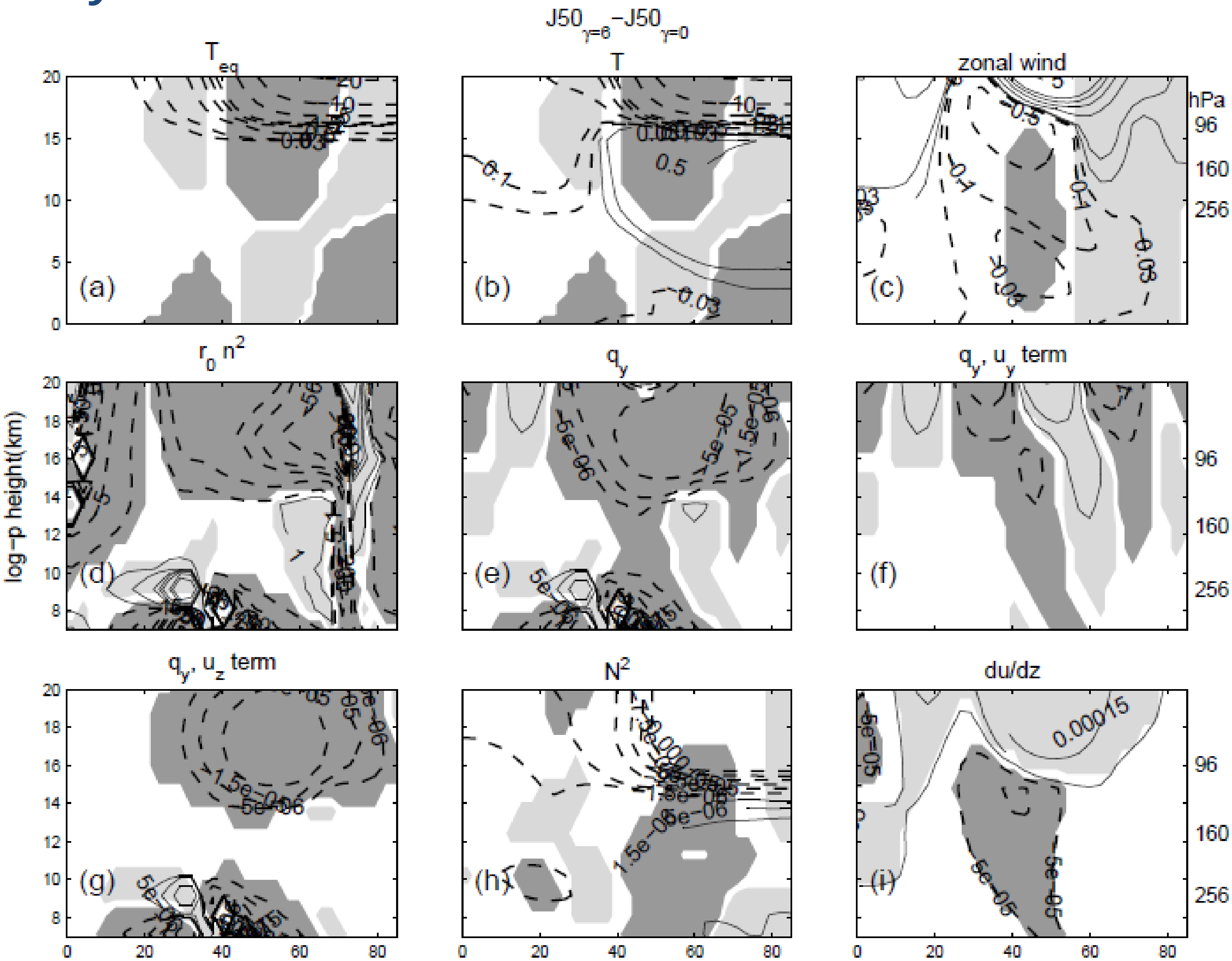

Figure 6: Axisymmetric circulation associated with a vortex

- Equator to Pole temperature gradient actually decreases.
- Zonal wind anomalies in midlatitudes is negative.
- Index of refraction might explain response

None of these 3 factors explain why J40 has the strongest response!!!

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Cause of stronger response for J40

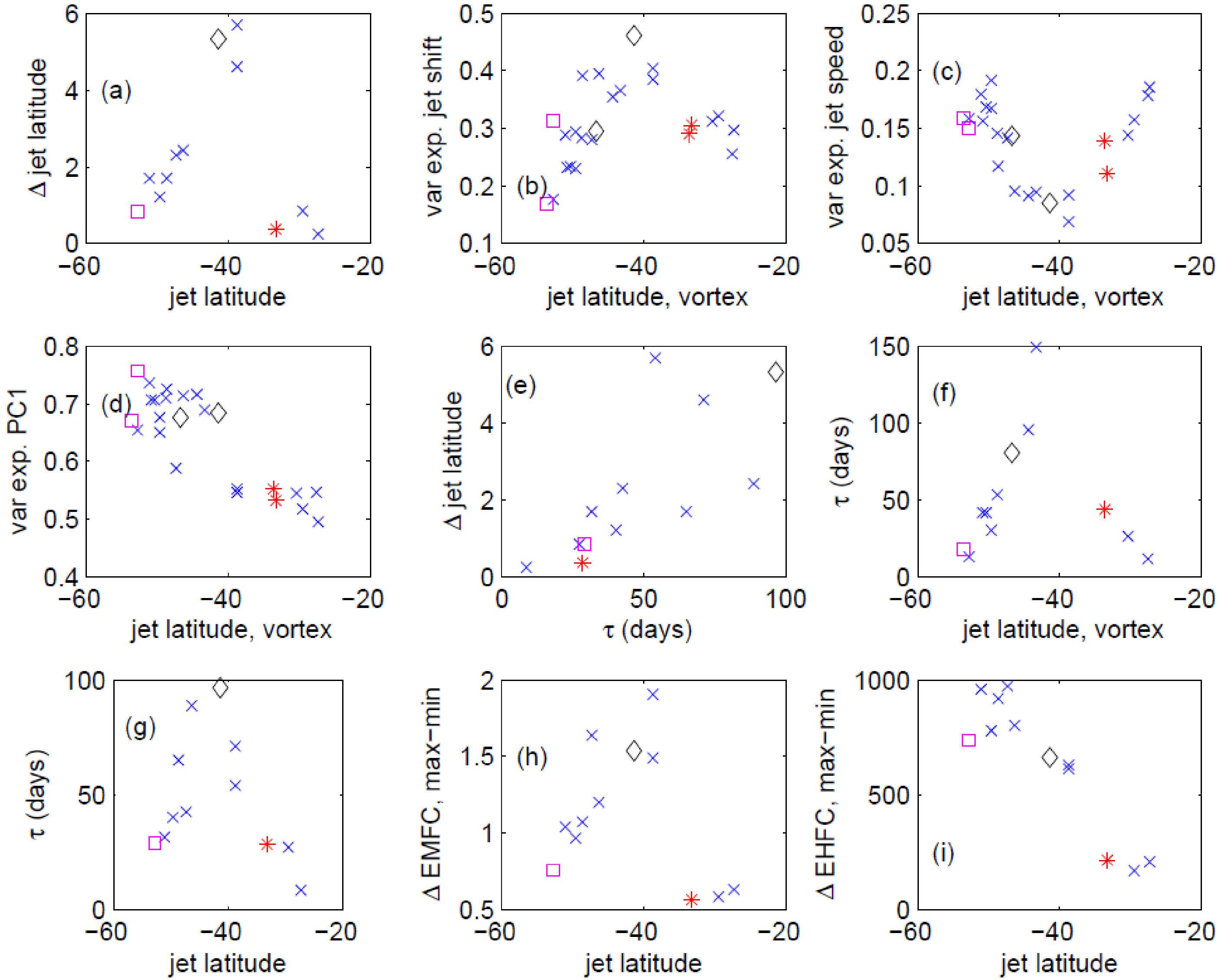
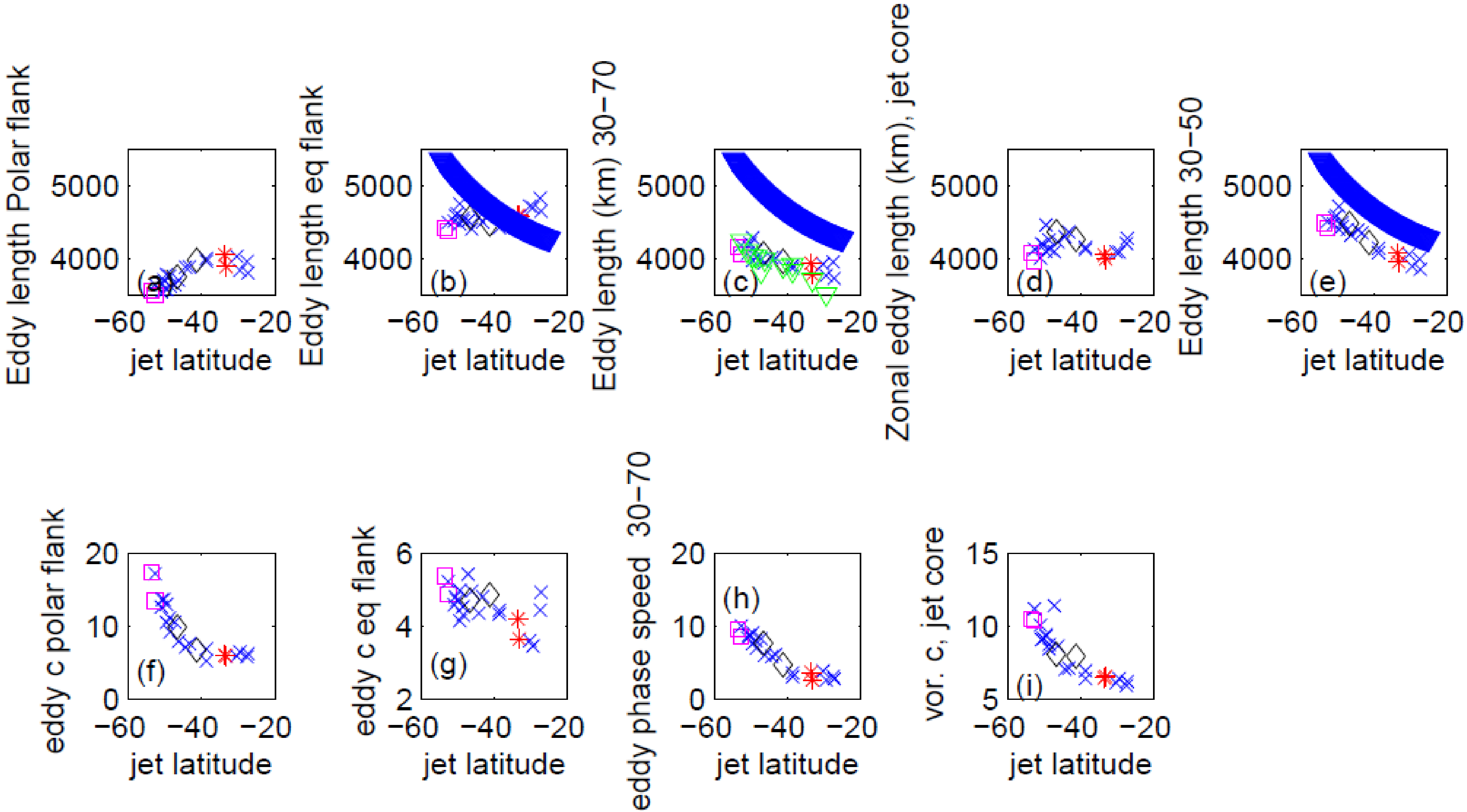


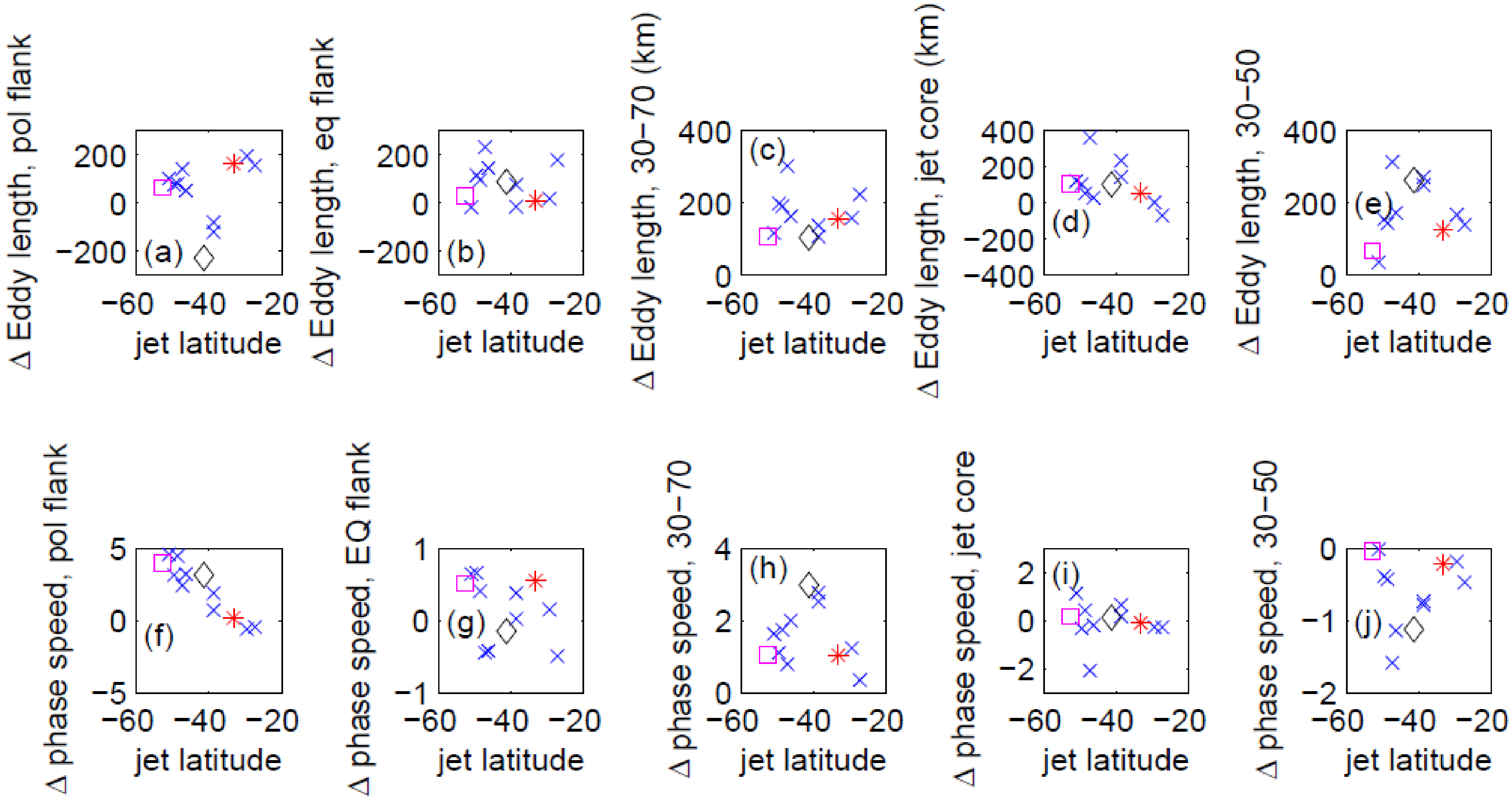
Fig 7: Jet persistence is controlled by latitude of jet, and persistence is weaker for a jet too close to the pole or to the subtropical jet

What about length scale and phase speeds?



In contrast to other work, eddy length scales do not increase, while eddy phase speeds do increase, with more poleward jets.

What about length scale and phase speeds?



Eddy length scale increases slightly due to the vortex, but little change (except for perhaps a slight increase) is seen in phase speed.

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Control Run Jets

Place jets at 30, 40, and 50.

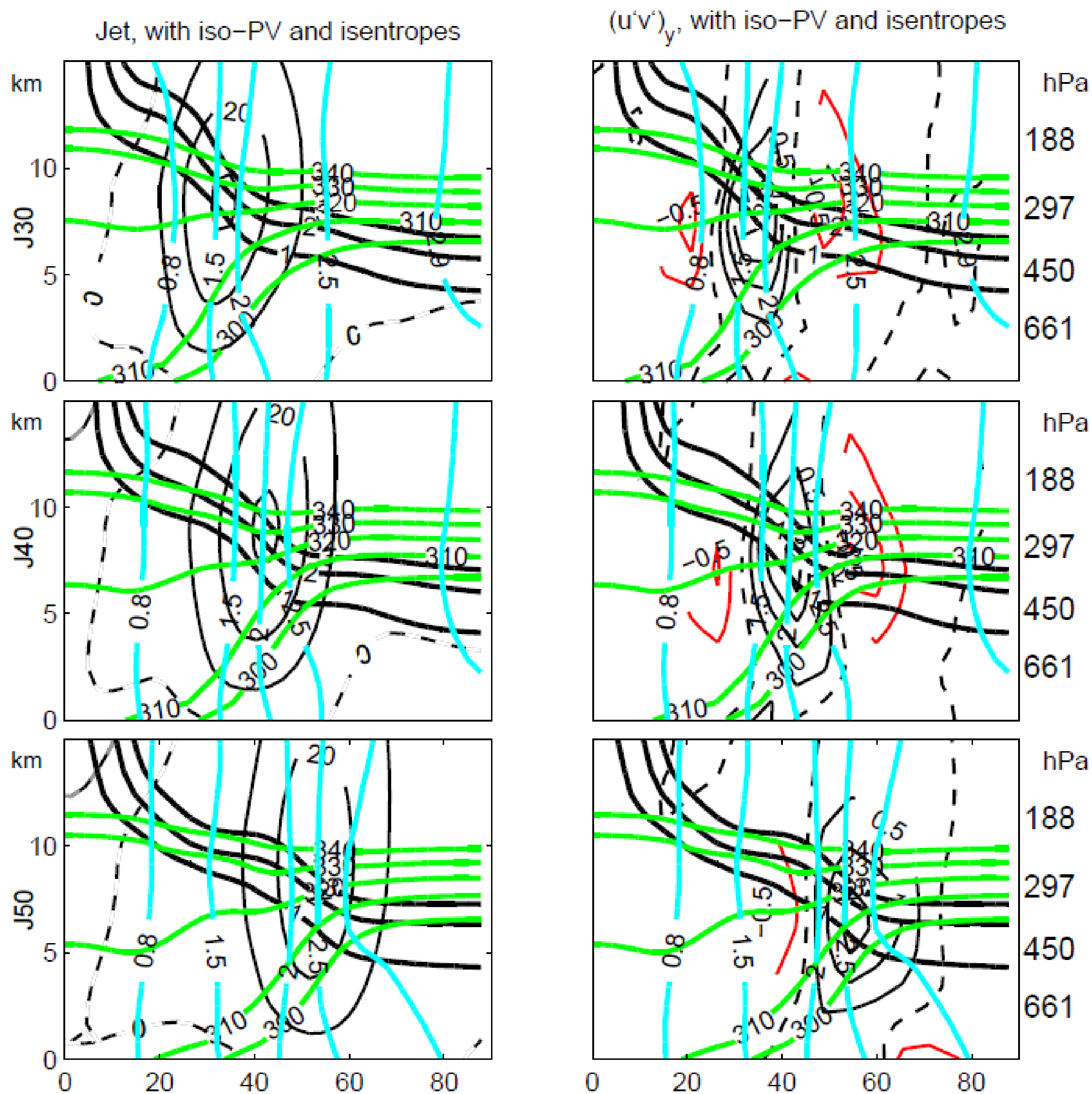
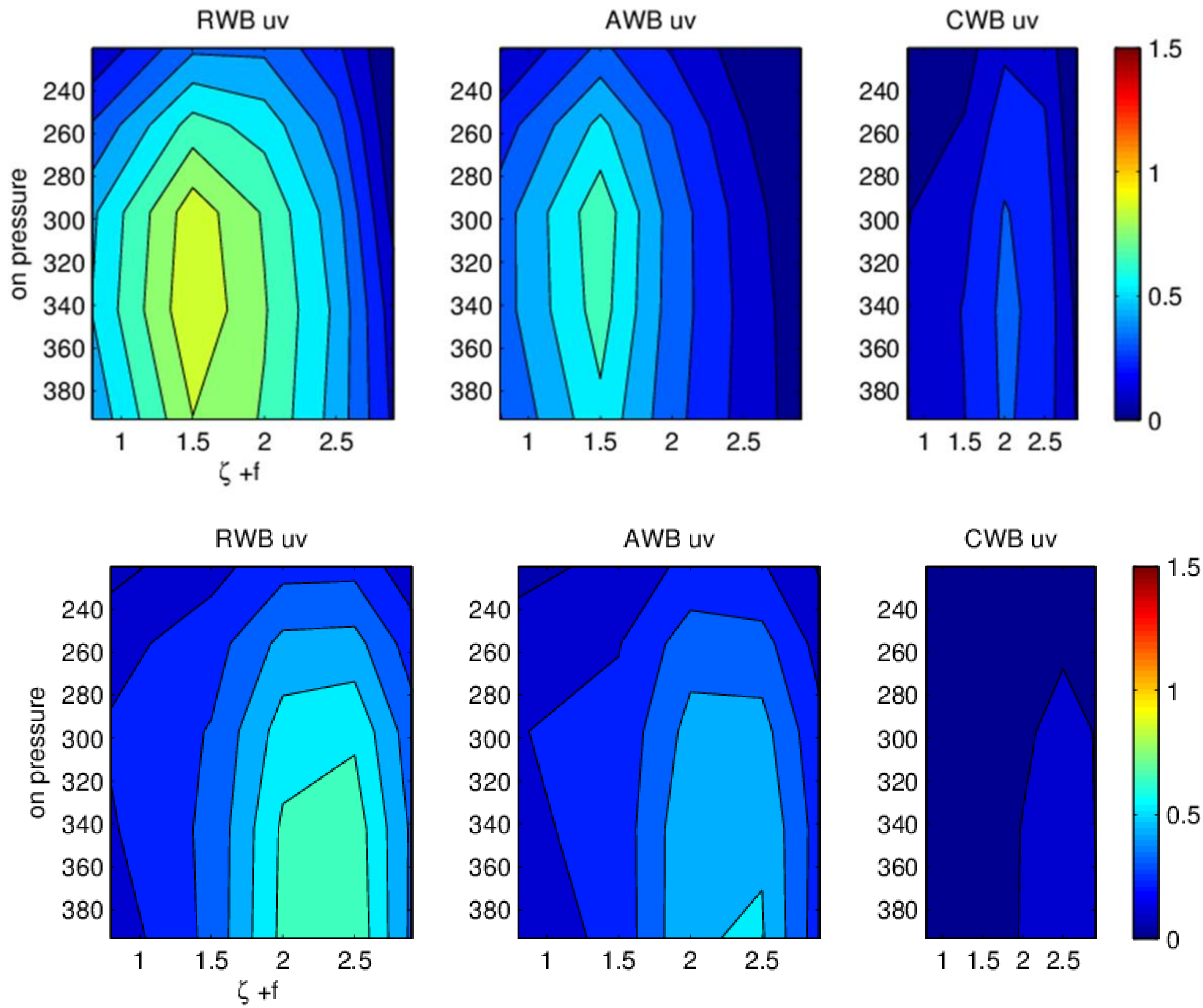


Fig 3:

J30 vs J50, absolute vorticity on pressure

J30

J50
Graph
versus
latitude

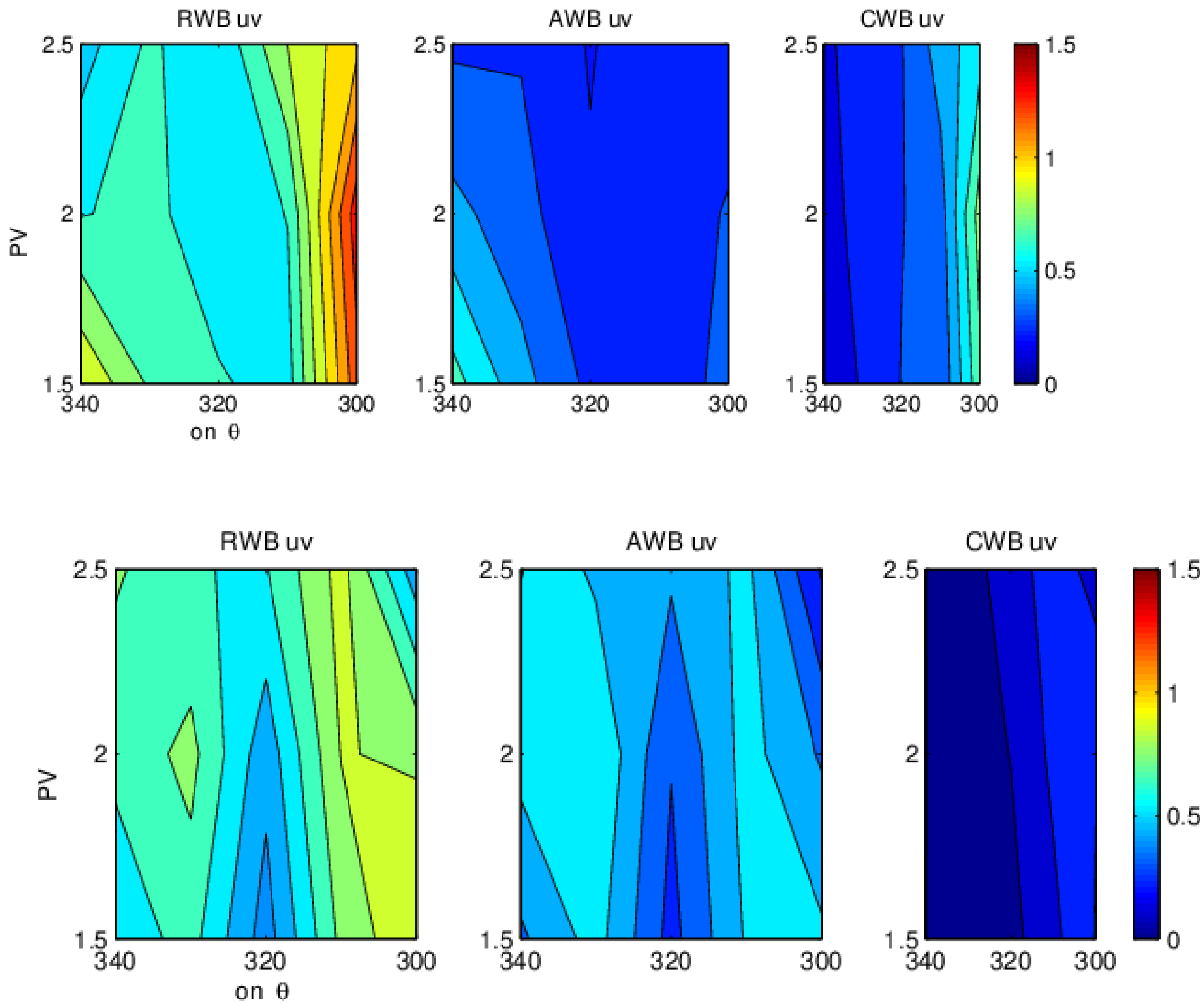


Eq
Pole

J30 vs J50, theta on PV

J30

J50



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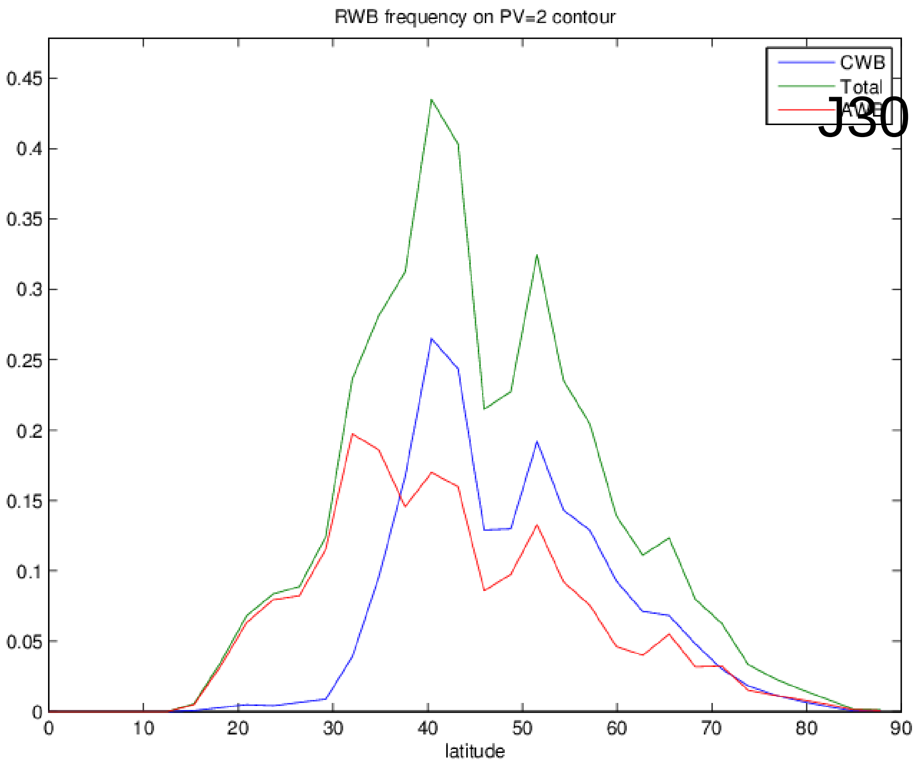
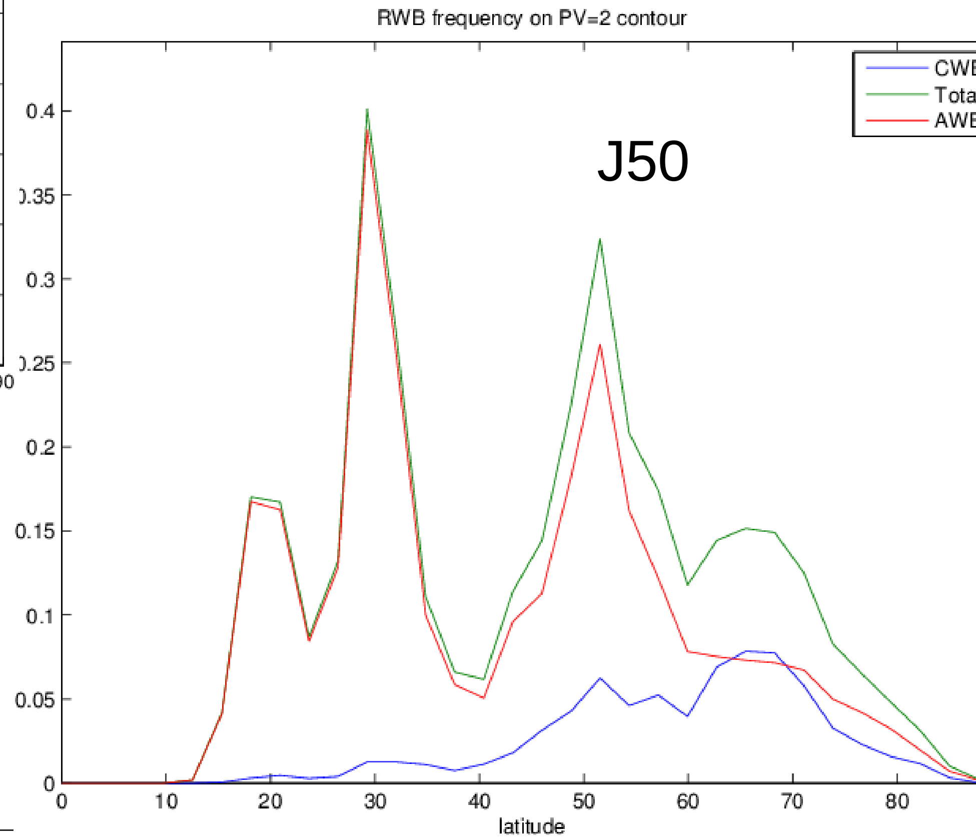
Eq

Pole

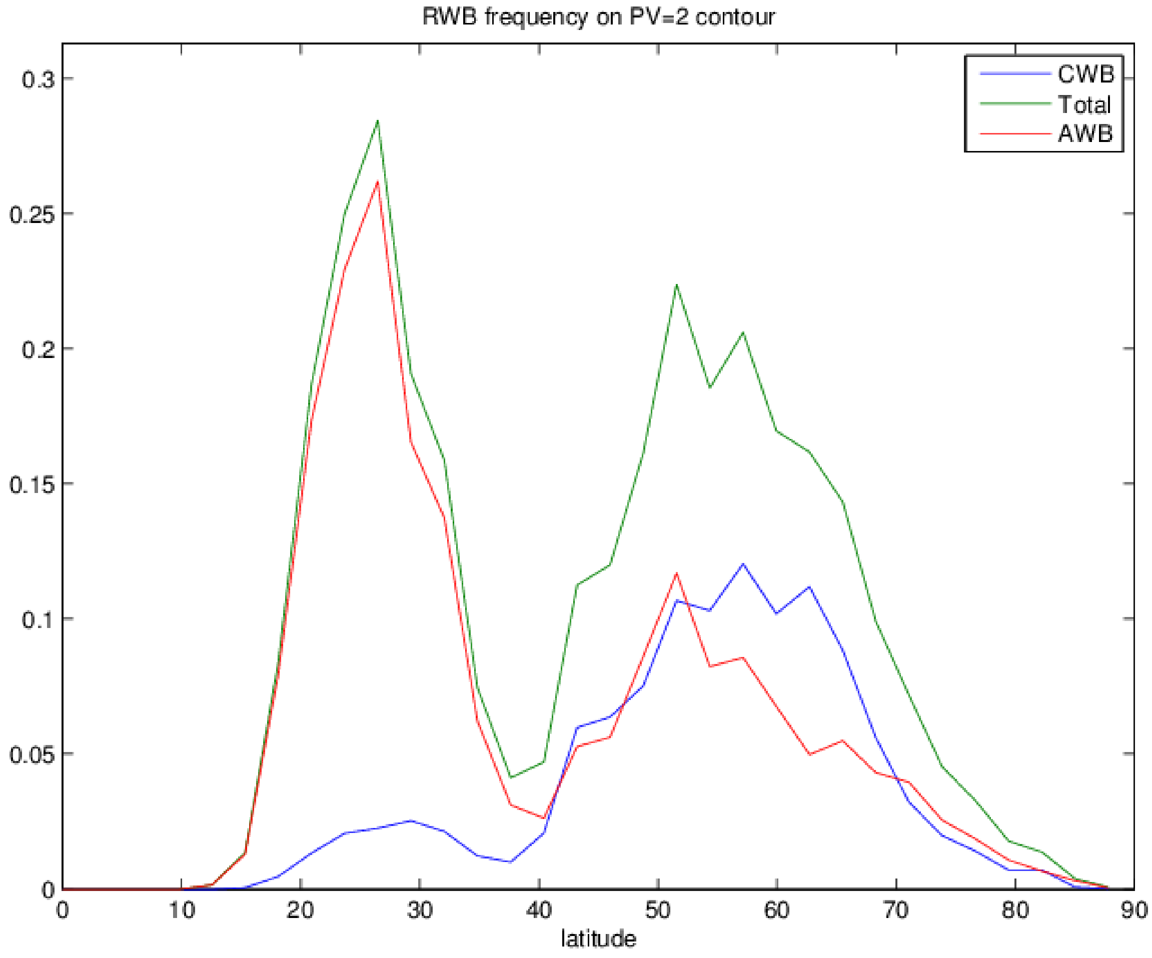
J30 vs J50, remap to latitude





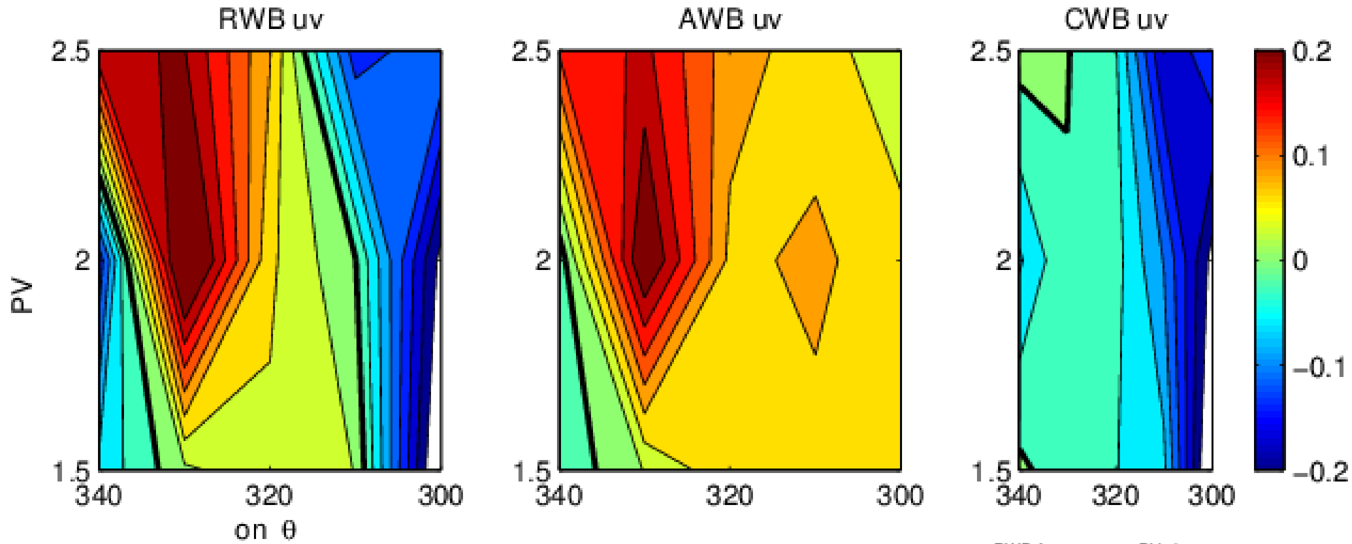
J40

No vortex



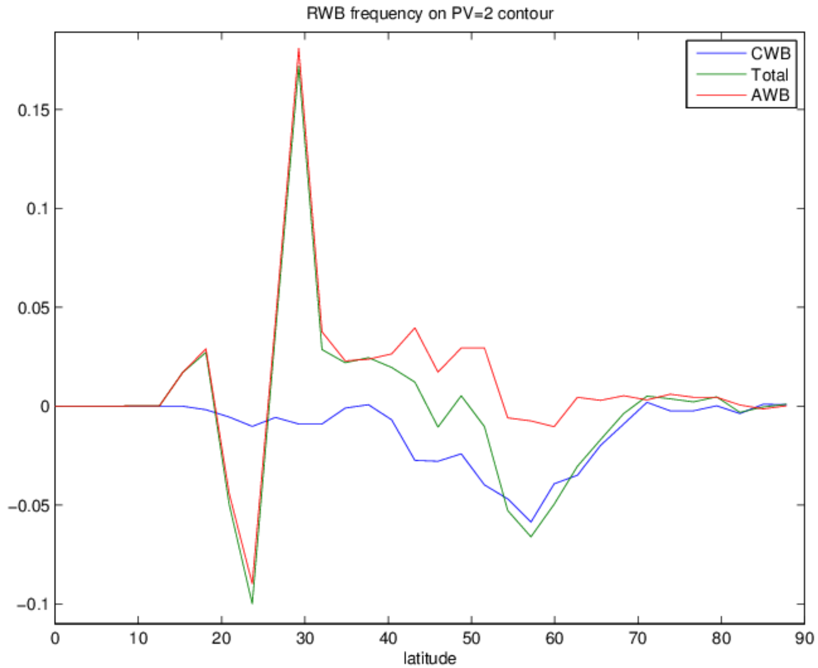
J40, vortex-no vortex

Theta on PV



Like Thando found

Abs. vor. on pressure



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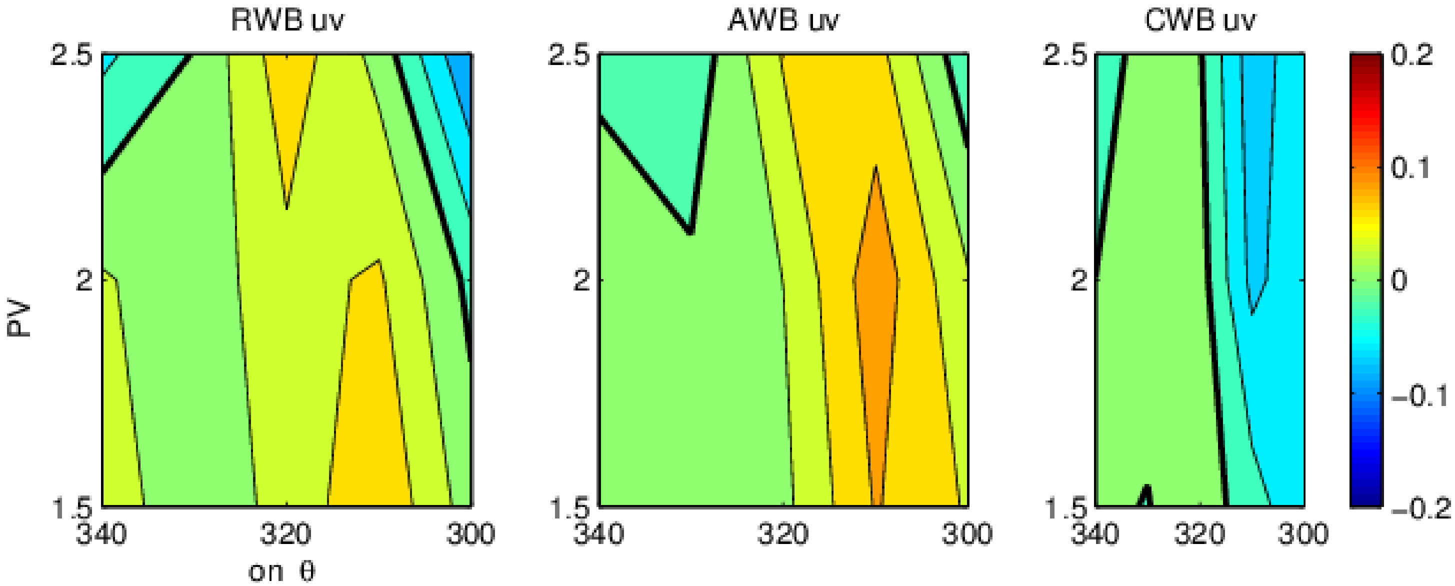
Eq Pole

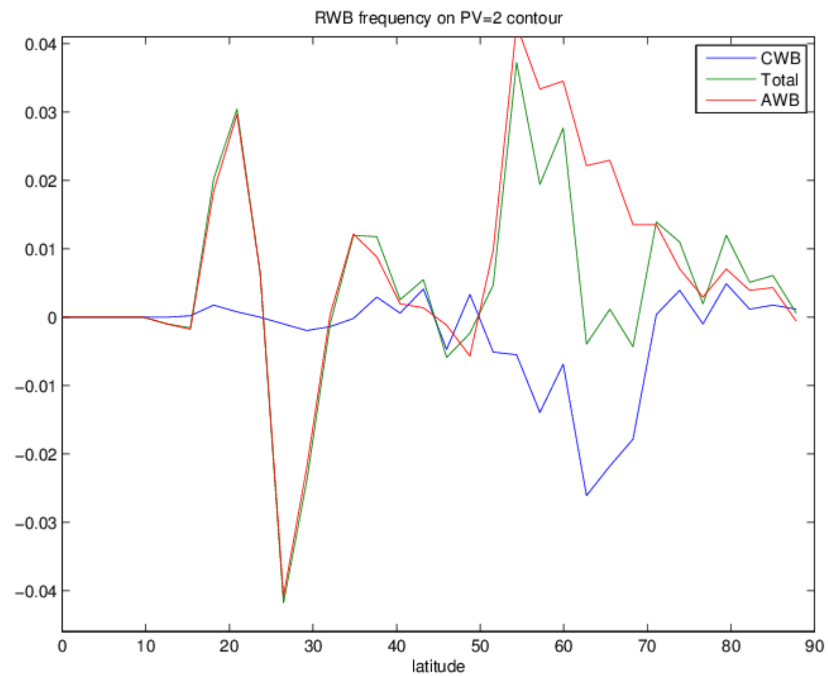
J50, vortex-no vortex

Theta
on PV



Eq —— Pole

Like Thando found, once you account for the fact that the 310 isentrope is near the jet position



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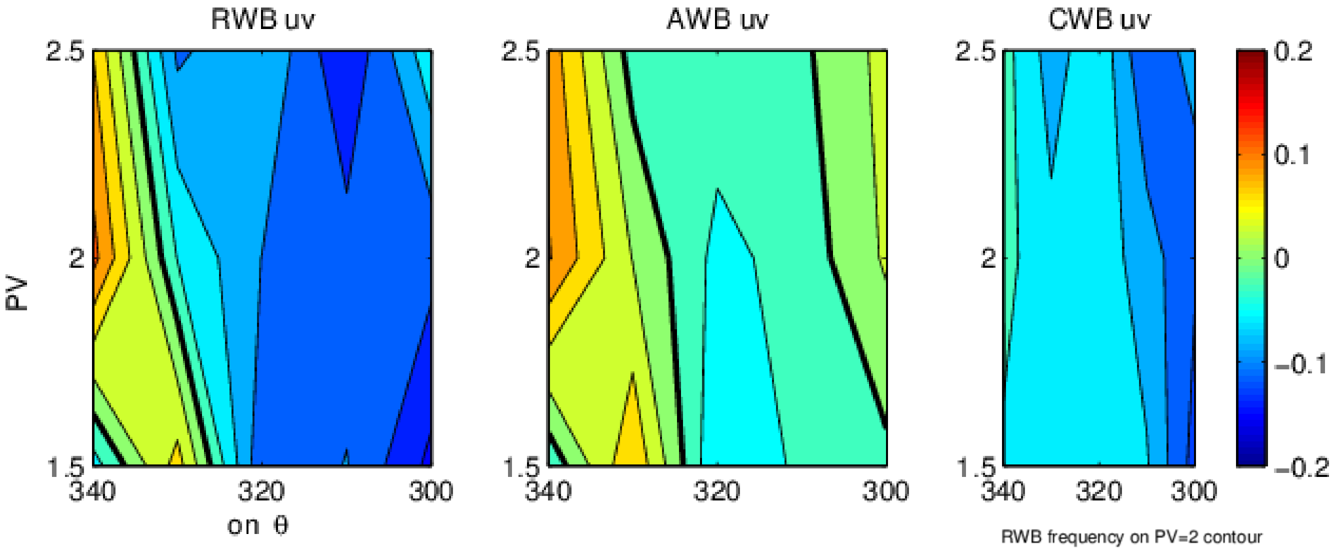
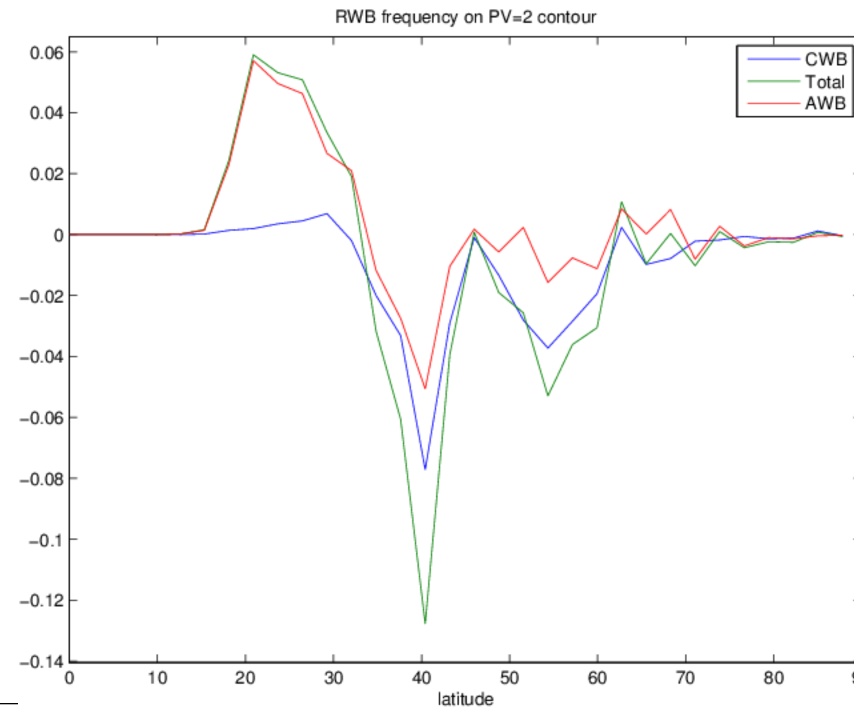
J30, vortex-no vortex

Theta
on PV



like
Thando
found

Abs. vor.
on
pressure



Eq Pole