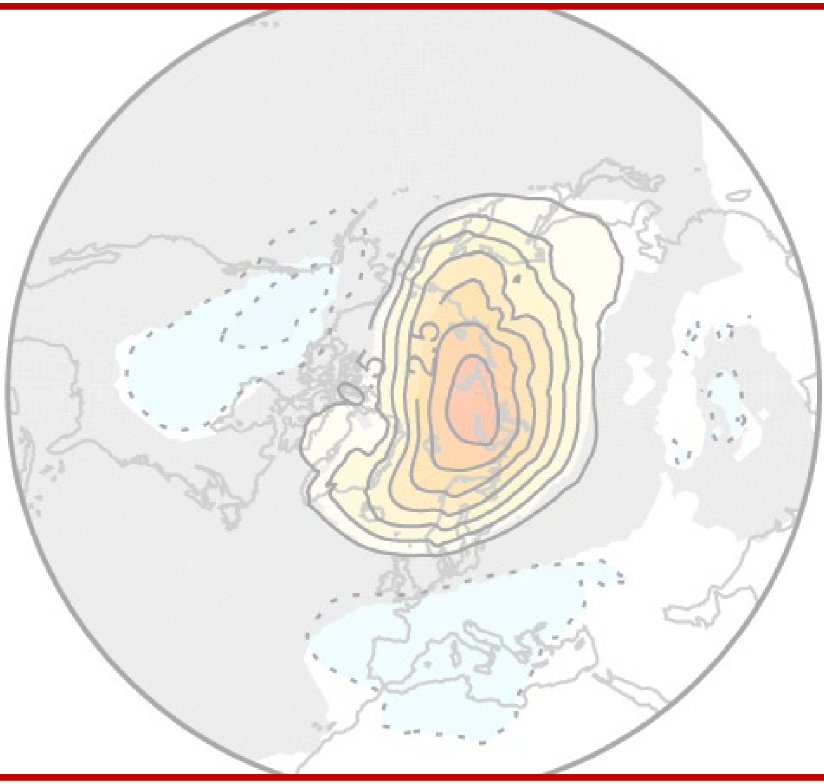
The downward influence of uncertainty in the Northern Hemisphere wintertime stratospheric polar vortex response to climate change



Isla Simpson, NCAR

Peter Hitchcock (LMD), Richard Seager (LDEO), Yutian Wu (LDEO), Patrick Callaghan (NCAR)

What role does the stratosphere play in contributing to the model spread in tropospheric circulation responses to climate change?

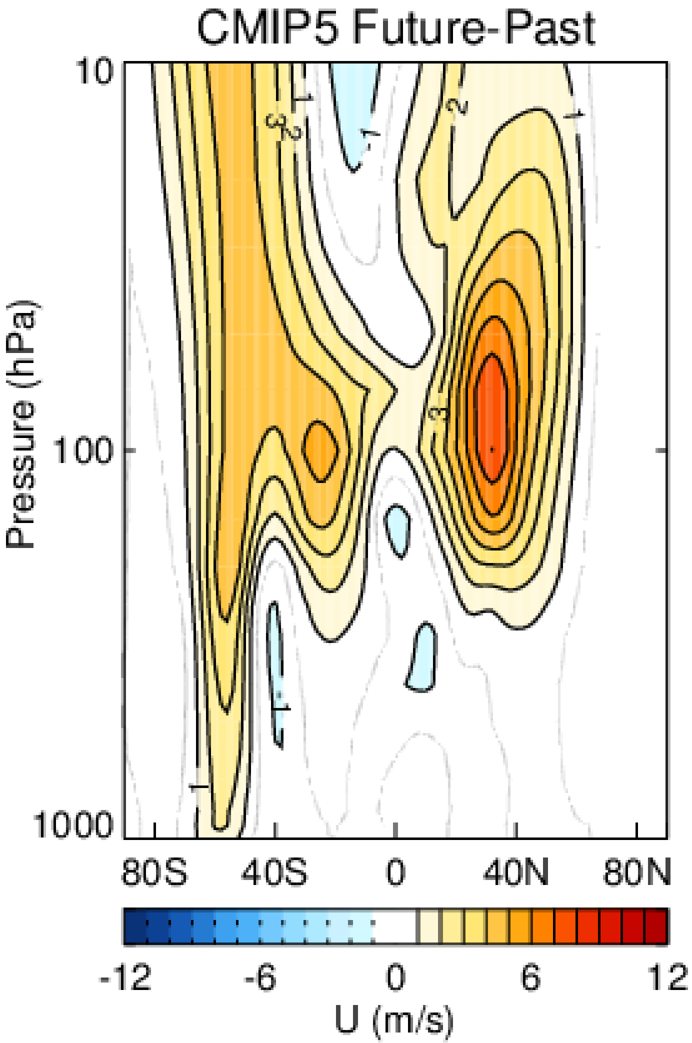
Predictions of the polar vortex response to climate change in the CMIP5 models

Future = 2070 – 2099 of RCP8.5

Past = 1979 – 2005 of historical

NH winter (DJF)

CMIP5 projections of the future of the stratospheric polar vortex



(see also Manzini et al 2014)

Zonal mean zonal wind (DJF)

Multi-model mean Future-Past difference

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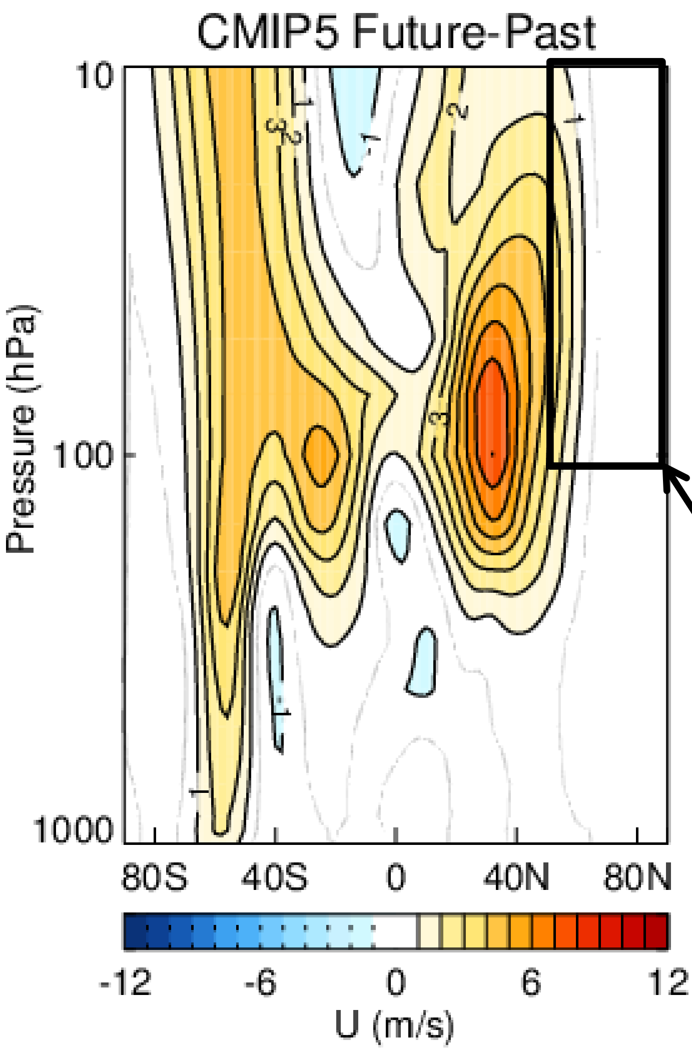

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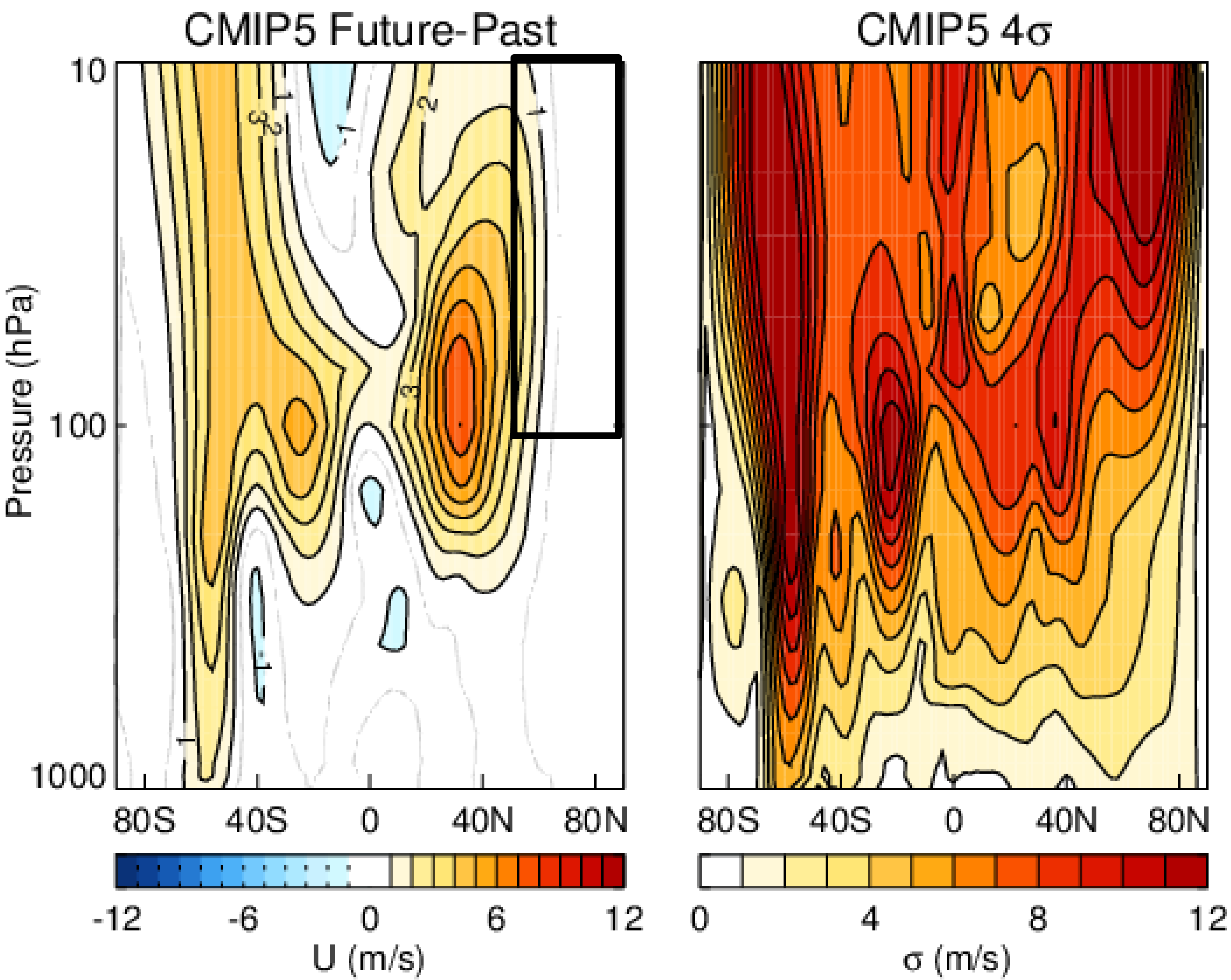
Zonal mean zonal wind (DJF)

Multi-model mean Future-Past difference

Not much change in the polar vortex region

CMIP5 projections of the future of the stratospheric polar vortex



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CMIP5 4σ range

(see also Manzini et al 2014)

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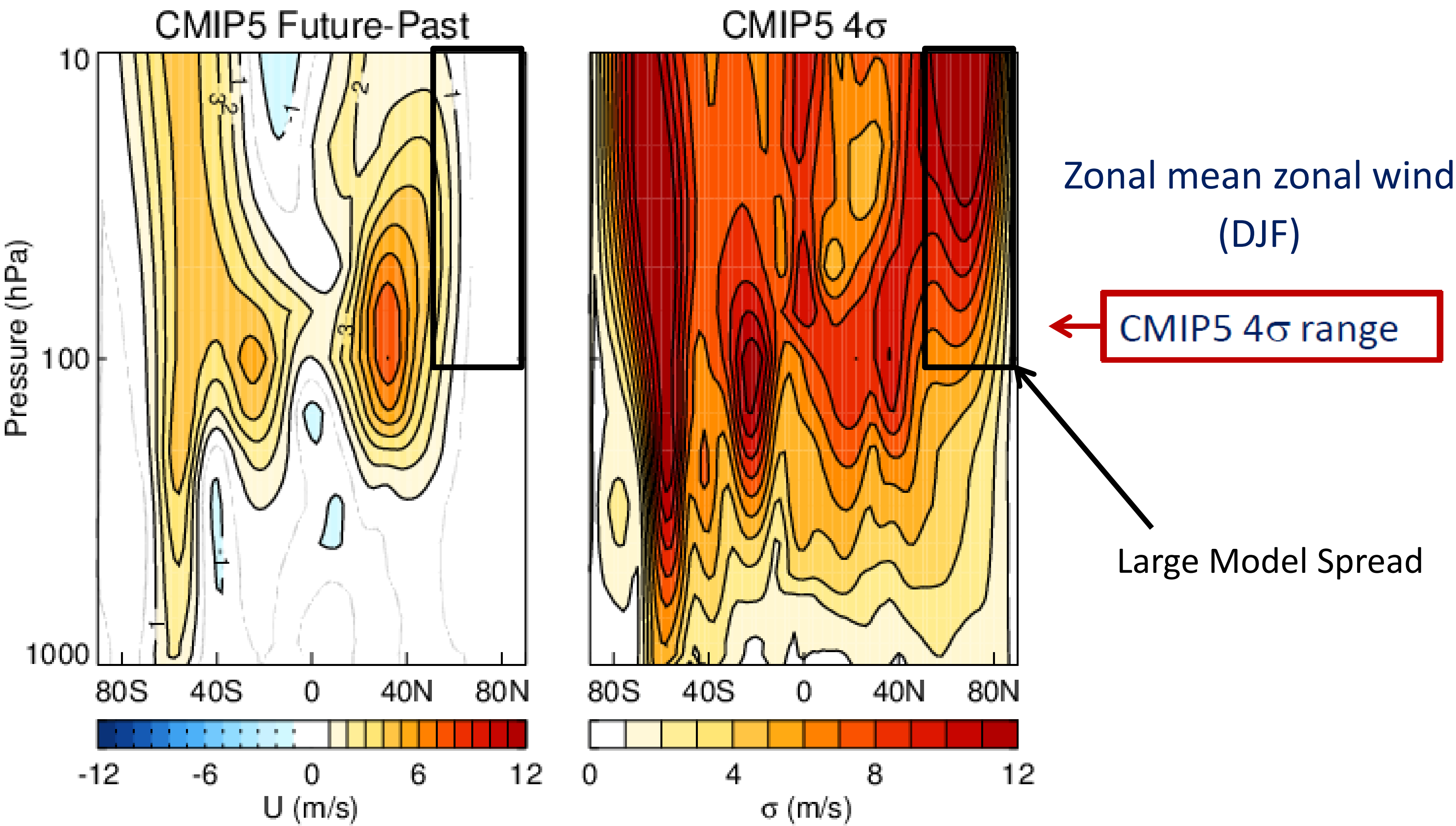

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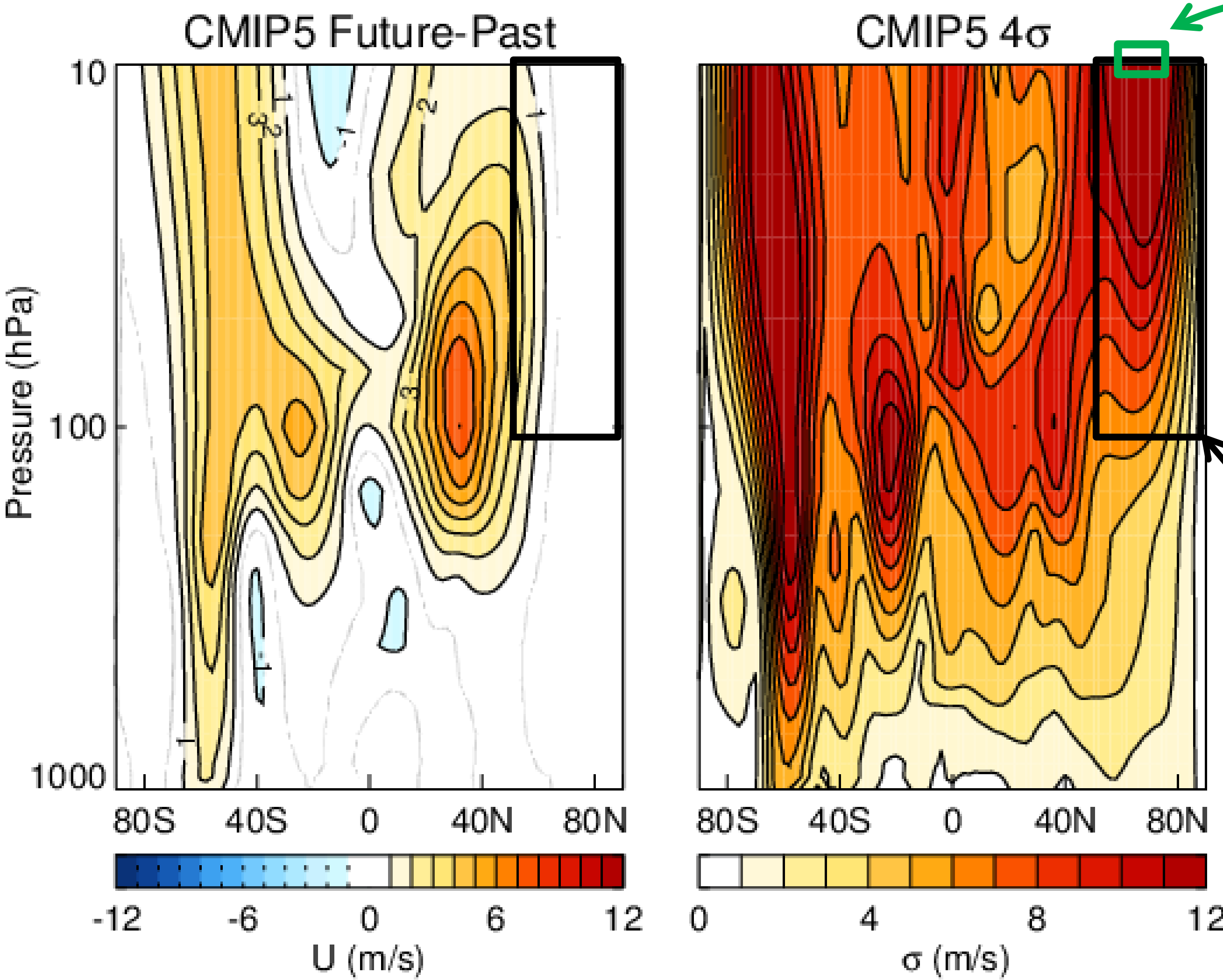


60N-75N, 10hPa u
(Polar Vortex Index)

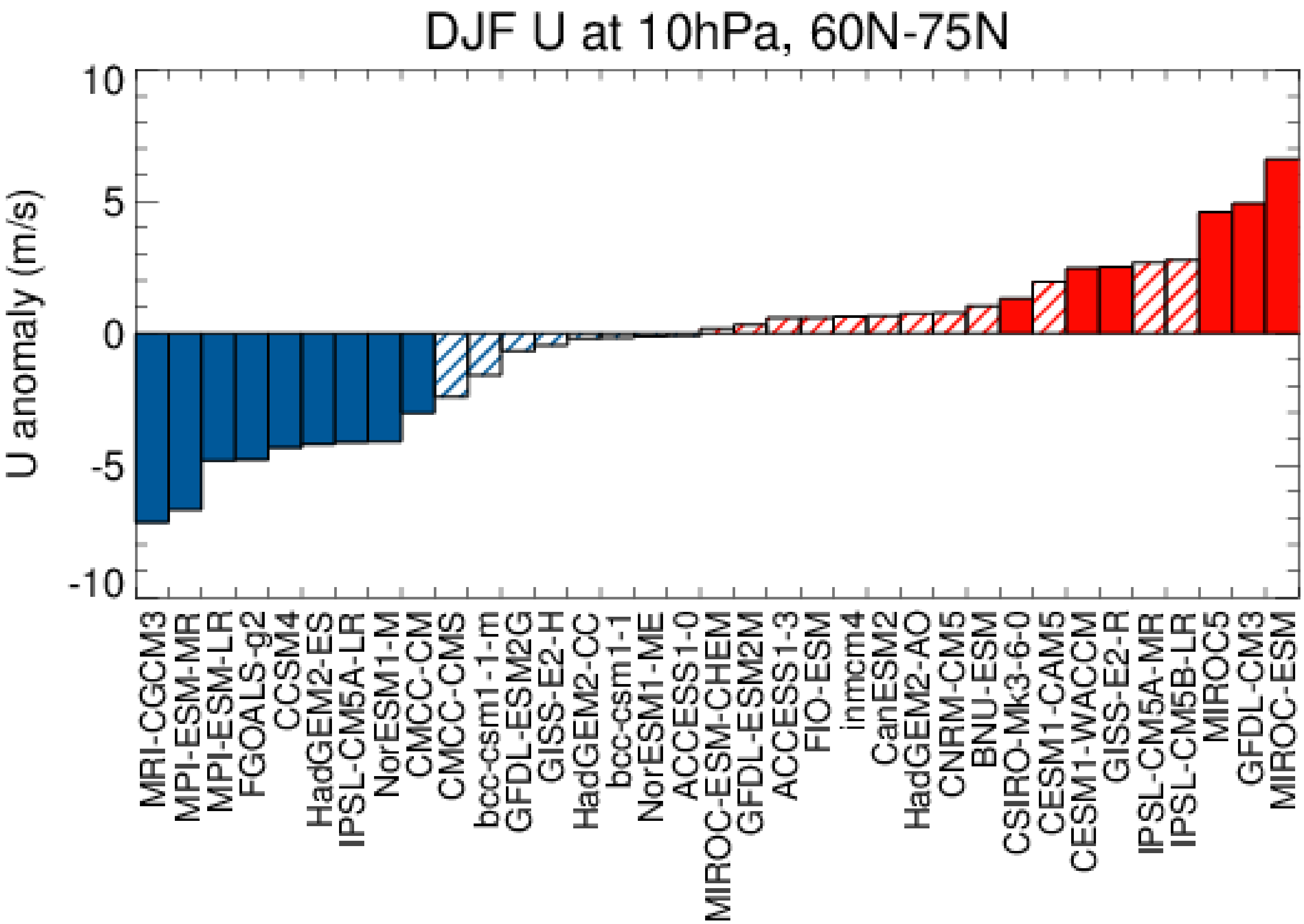
Zonal mean zonal wind
(DJF)

CMIP5 4σ range

Large Model Spread

(see also Manzini et al 2014)

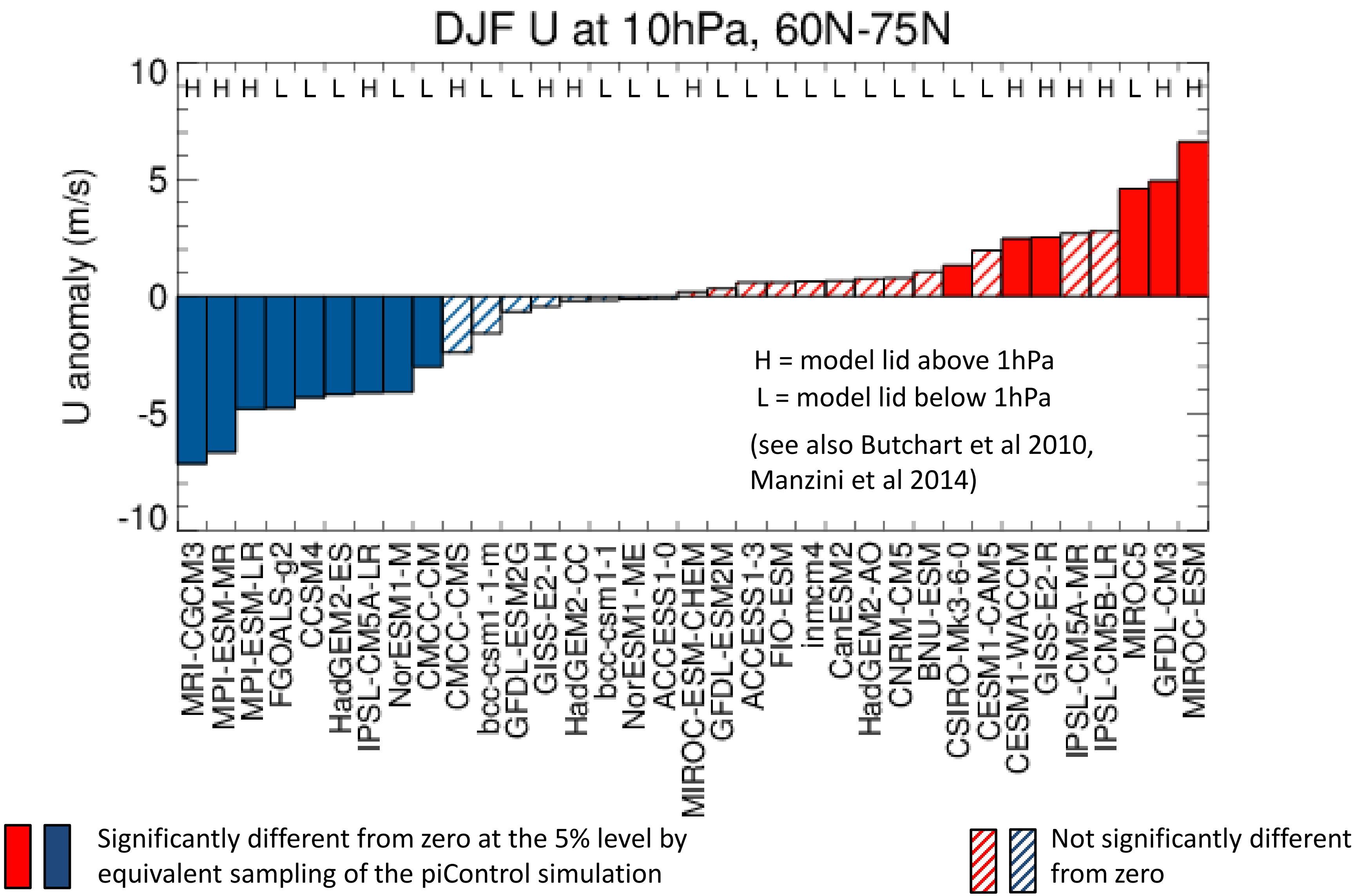
CMIP5 projections of the future of the stratospheric polar vortex



Significantly different from zero at the 5% level by equivalent sampling of the piControl simulation

Not significantly different from zero

CMIP5 projections of the future of the stratospheric polar vortex



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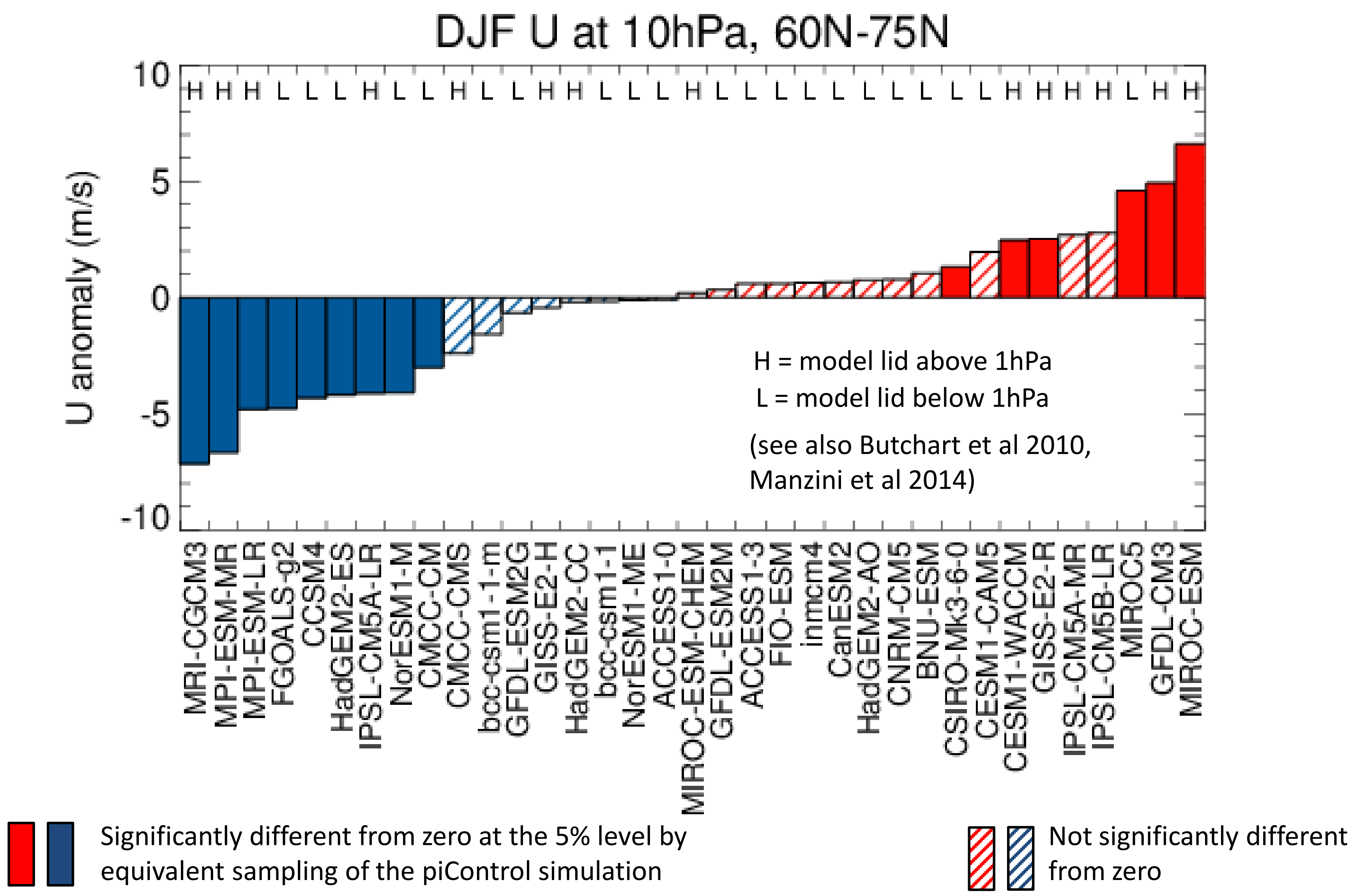

CMIP5 projections of the future of the stratospheric polar

Proposed reasons for this spread…

- Sigmond and Scinocca (2010) – Differences in gravity wave tuning → different mean state → different propagation response to climate change.
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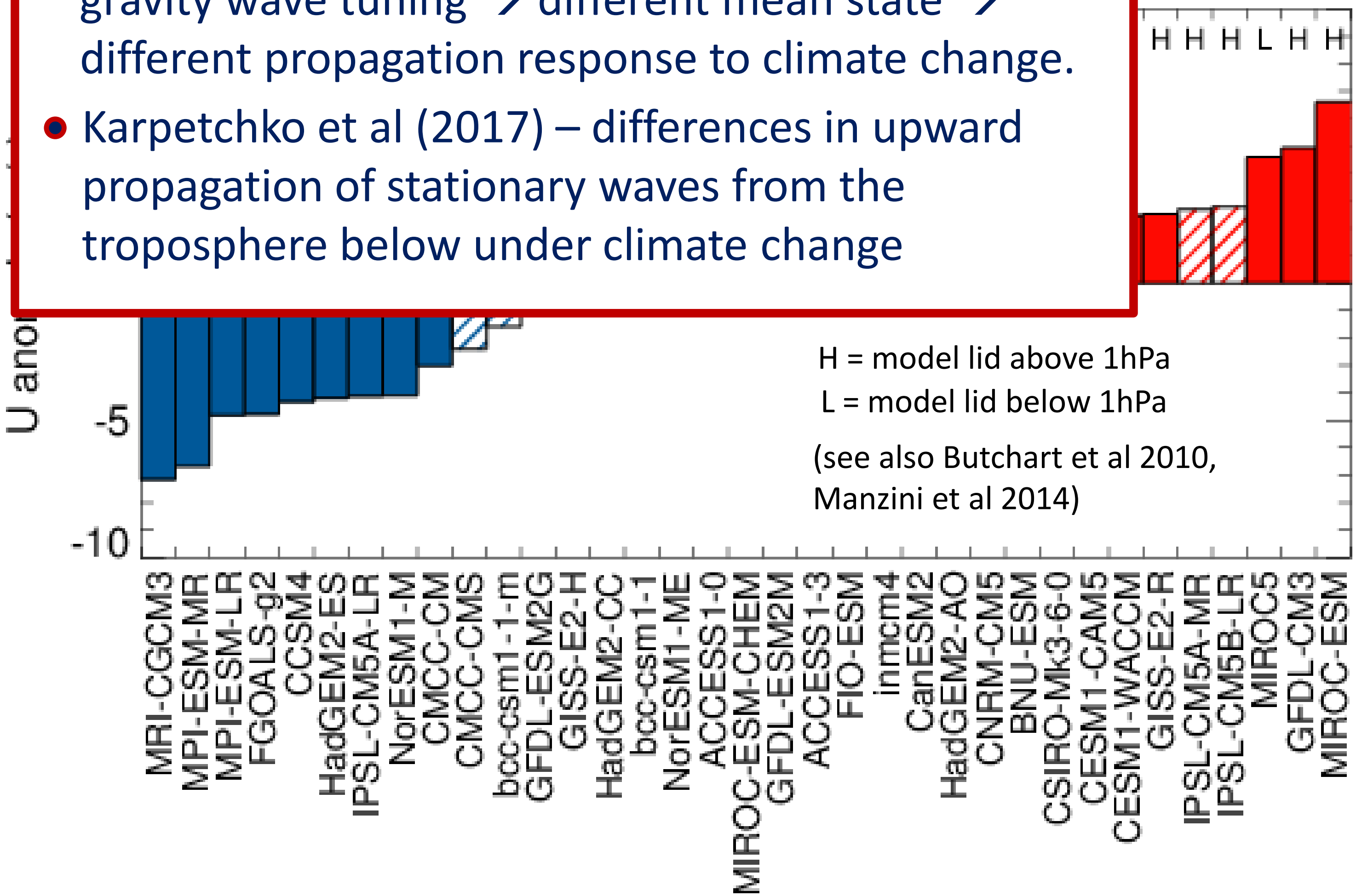

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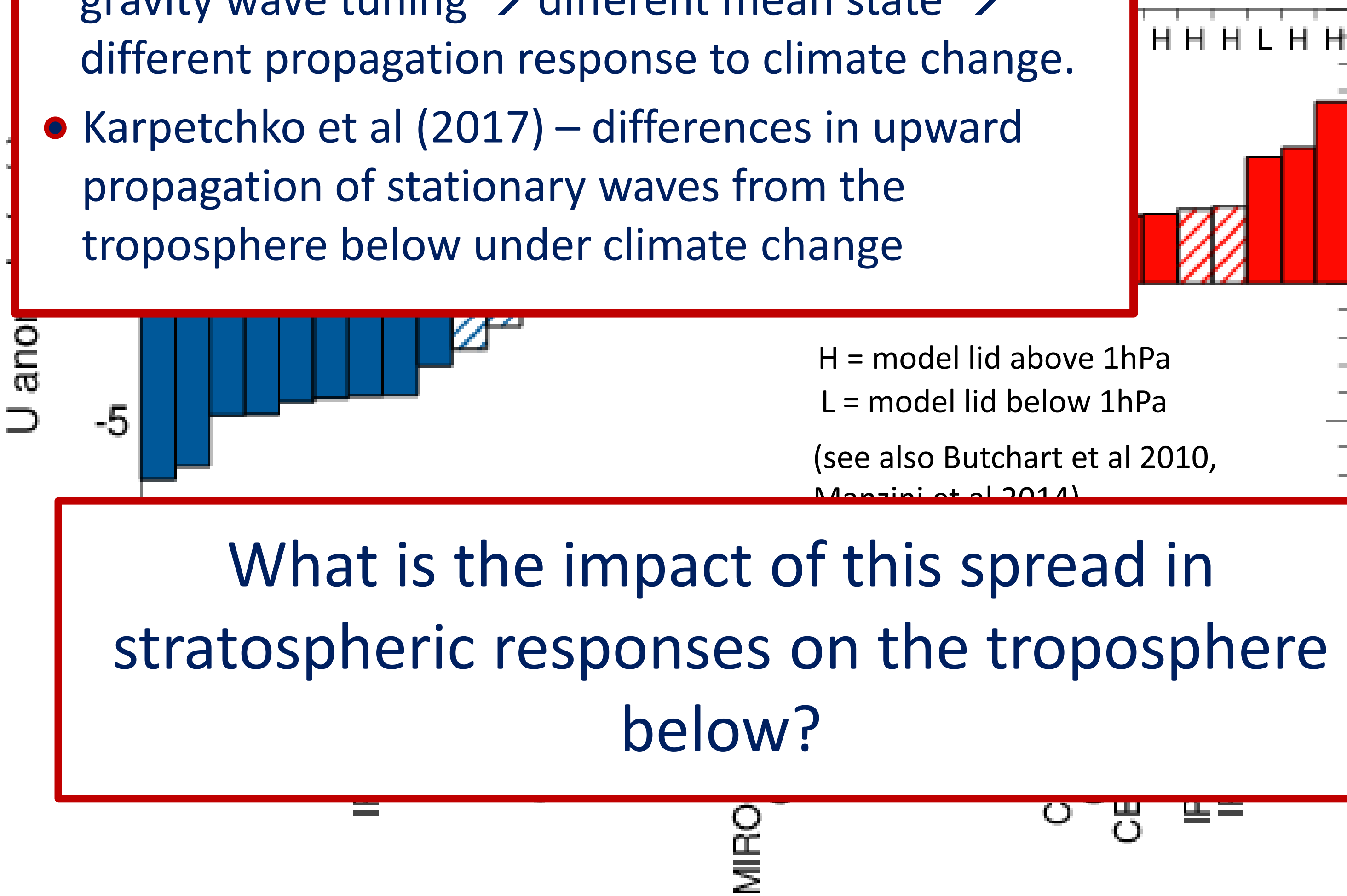

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What is the impact of this spread in stratospheric responses on the troposphere below?

Significantly different from zero at the 5% level by equivalent sampling of the piControl simulation

Not significantly different from zero

Manzini et al (2014) – CMIP5 analysis

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD021403

Northern winter climate change: Assessment of uncertainty in CMIP5 projections related to stratosphere-troposphere coupling

E. Manzini[1], A. Yu. Karpechko[2], J. Anstey[3], M. P. Baldwin[4], R. X. Black[5], C. Cagnazzo[6], N. Calvo[7], A. Charlton-Perez[8], B. Christiansen[9], Paolo Davini[10], E. Gerber[11], M. Giorgetta[1], L. Gray[3], S. C. Hardiman[12], Y.-Y. Lee[13], D. R. Marsh[14], B. A. McDaniel[15], A. Purich[16], A. A. Scaife[12], D. Shindell[17], S.-W. Son[18], S. Watanabe[19], and G. Zappa[20]

Key Points:

- Stratospheric easterly change is common feature in future climate projections
- Significant intermodel spread in stratospheric northern winter climate change
- Importance of stratospheric easterly

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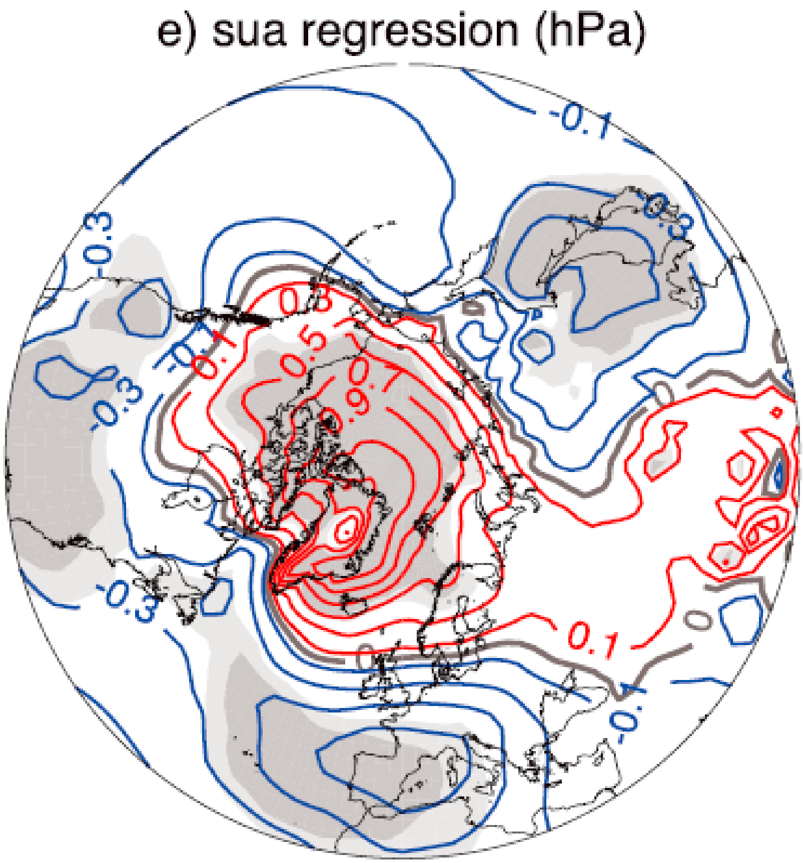
Performed linear regressions, across models, of fields onto a measure of the change in the polar vortex (zonal mean zonal wind at 10hPa, 70N-80N).

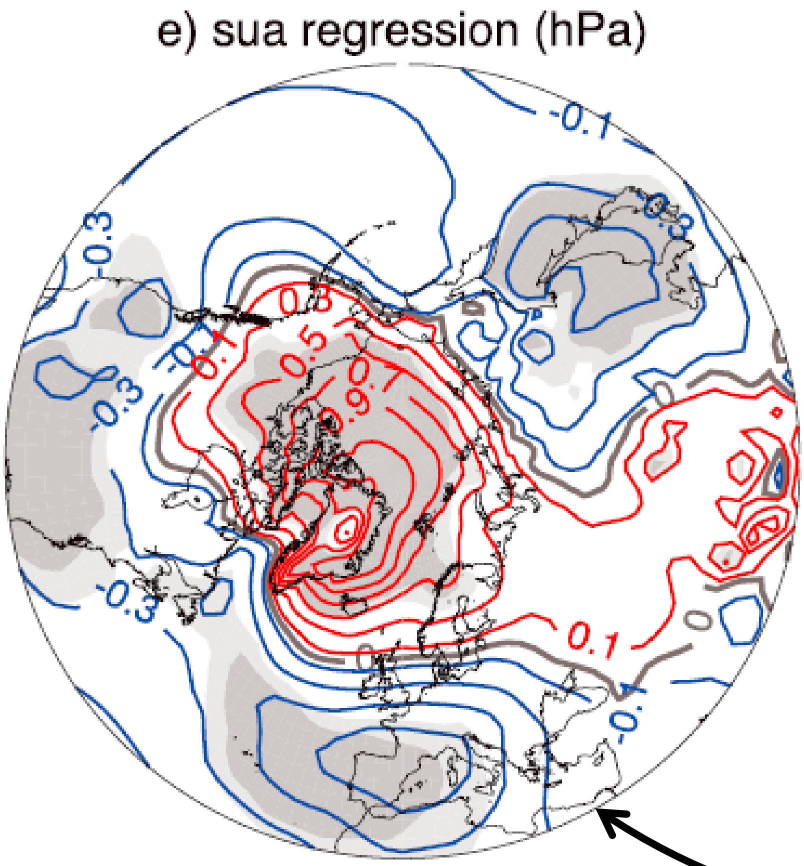
After first regressing out contributions to inter-model spread from tropical upper tropospheric warming and Arctic amplification.

Manzini et al (2014) – CMIP5 analysis



Regression of sea level pressure onto the index of the polar vortex response (x-1)

Manzini et al (2014) – CMIP5 analysis

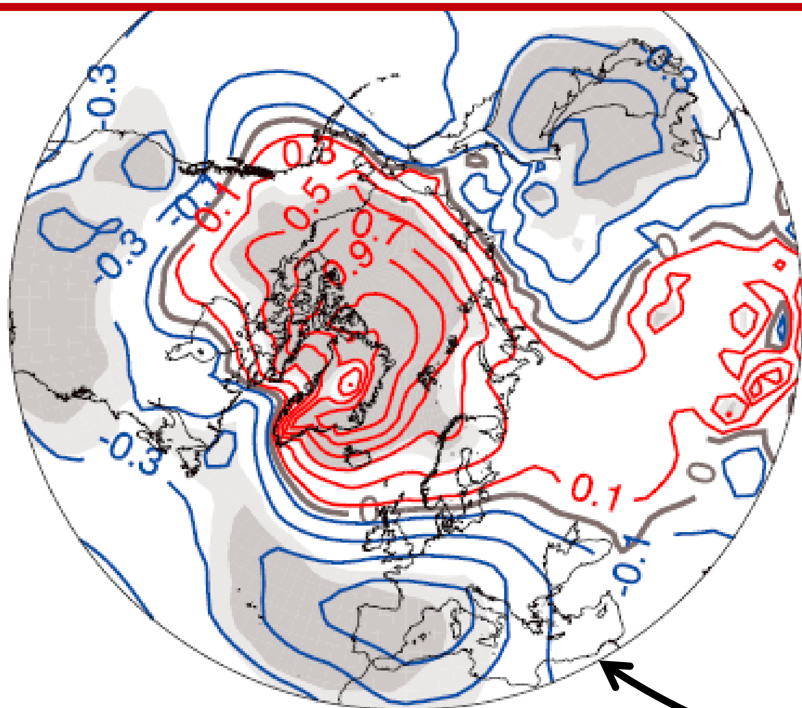


Regression of sea level pressure onto the index of the polar vortex response (x-1)

With a relative weakening of the polar vortex comes a relative increase in Arctic SLP and decrease to the South (negative NAO)

Manzini et al (2014) – CMIP5 analysis

- Indications that there is a relationship between how a model's polar vortex response to climate change and the circulation in the troposphere → contributing to intermodel spread



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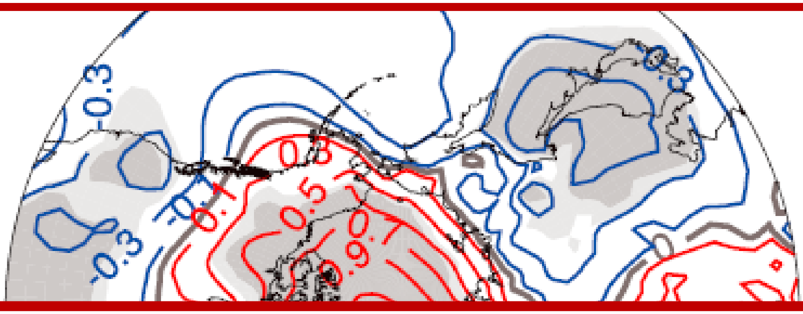

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Stratosphere → Troposphere

Troposphere → Stratosphere

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Idealized experiments with CESM

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- Quantify the magnitude of this effect in a controlled model setting

Idealized experiments with CESM

- A 46 level version extending to 0.3hPa (Richter et al 2015)
- Fully coupled

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↑

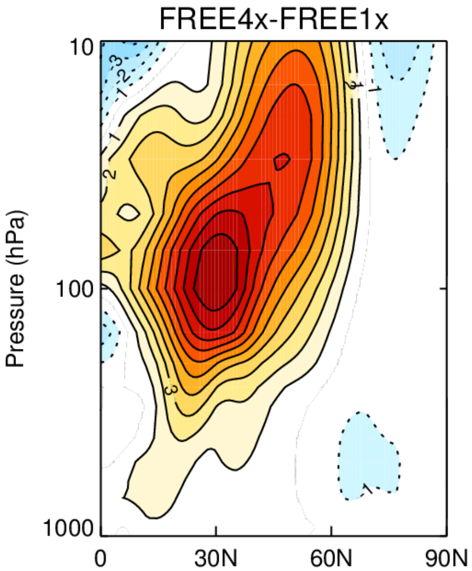
A simple linear relaxation of the zonal mean winds and temperature toward a specified climatological target state. Full nudging above 28hPa, linearly decreasing to zero nudging below 64hPa.

The Experiments

4xCO2-1xCO2 difference in zonal mean zonal wind

Free running

FREE4x – FREE1x

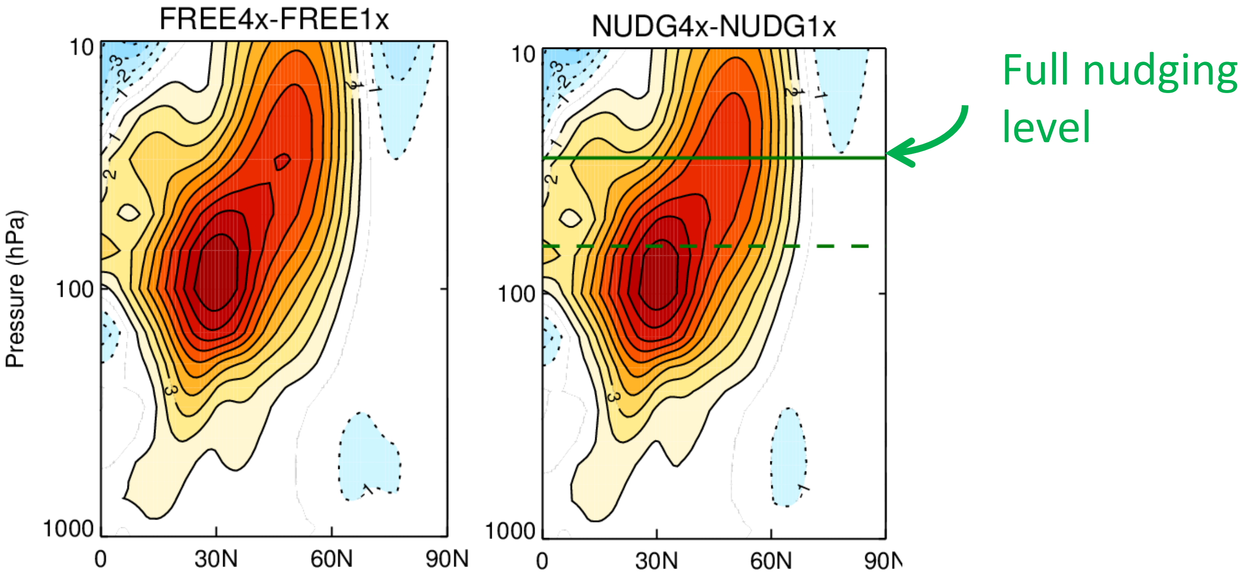


The Experiments

4xCO2-1xCO2 difference in zonal mean zonal wind

Free running — FREE4x – FREE1x

Nudged — NUDG4x – NUDG1x



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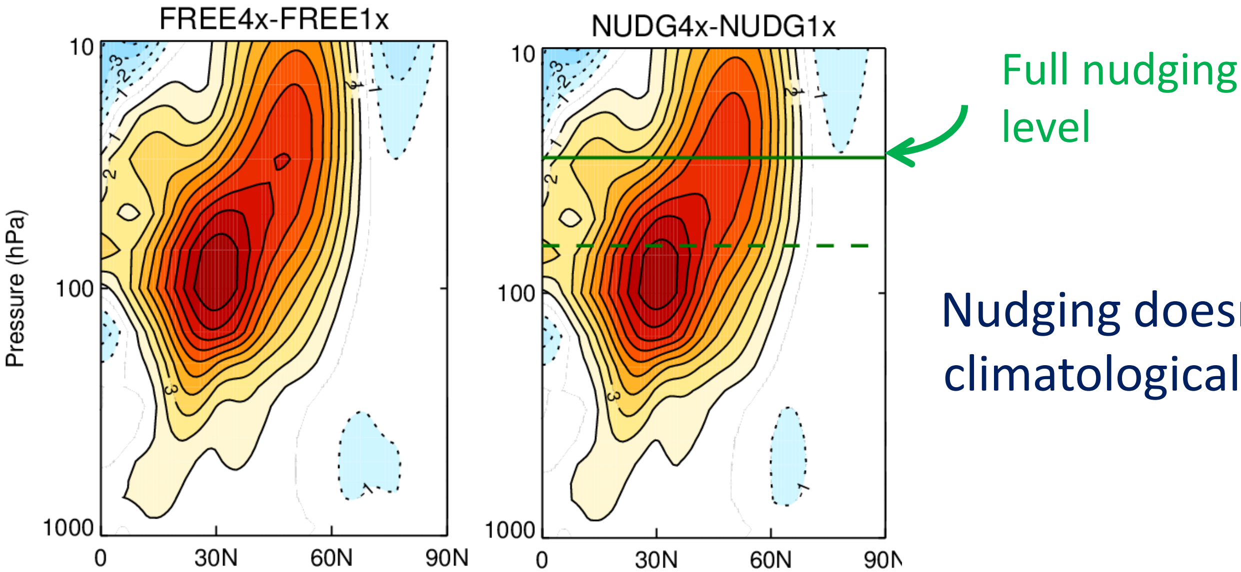
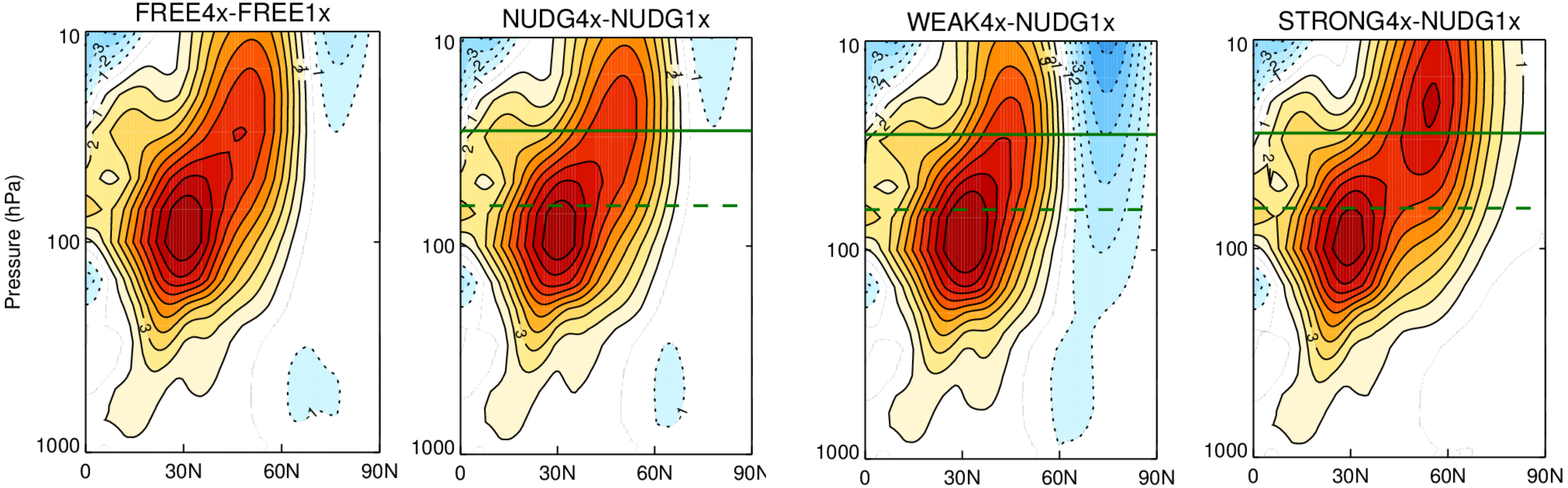


Nudging doesn't substantially affect the climatological tropospheric response to 4xCO2

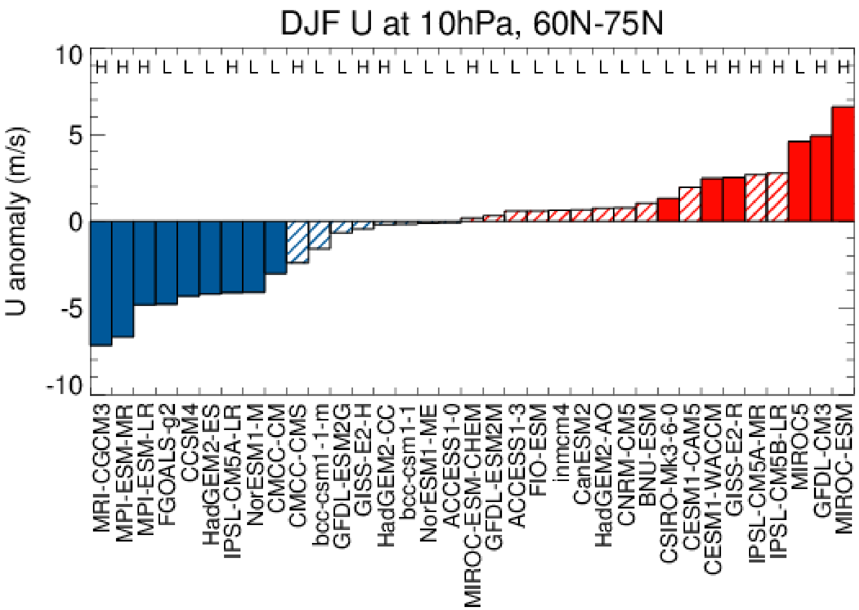
The Experiments

4xCO2-1xCO2 difference in zonal mean zonal wind

Free running	Nudged	Weakened vortex	Strengthened vortex
FREE4x – FREE1x	NUDG4x – NUDG1x	WEAK4x – NUDG1x	STRONG4x – NUDG1x



Designing the perturbations



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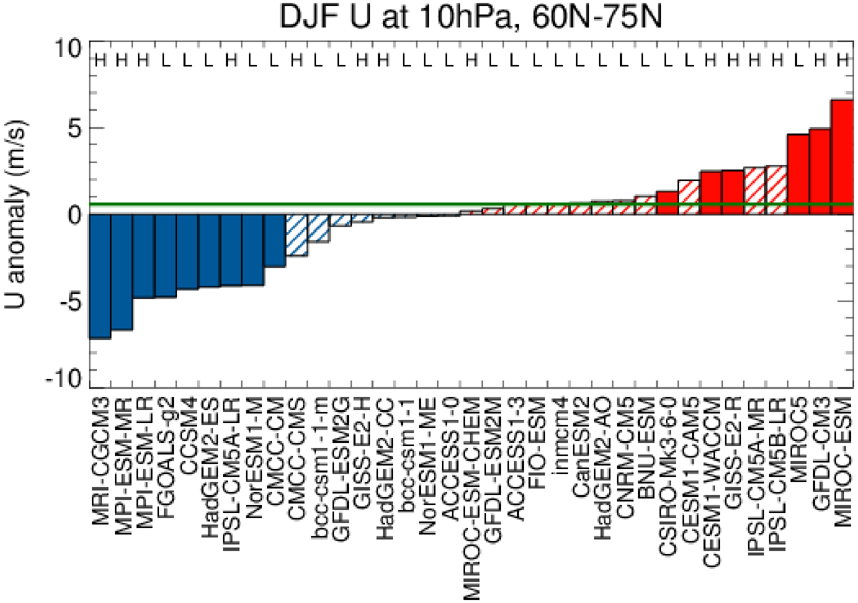
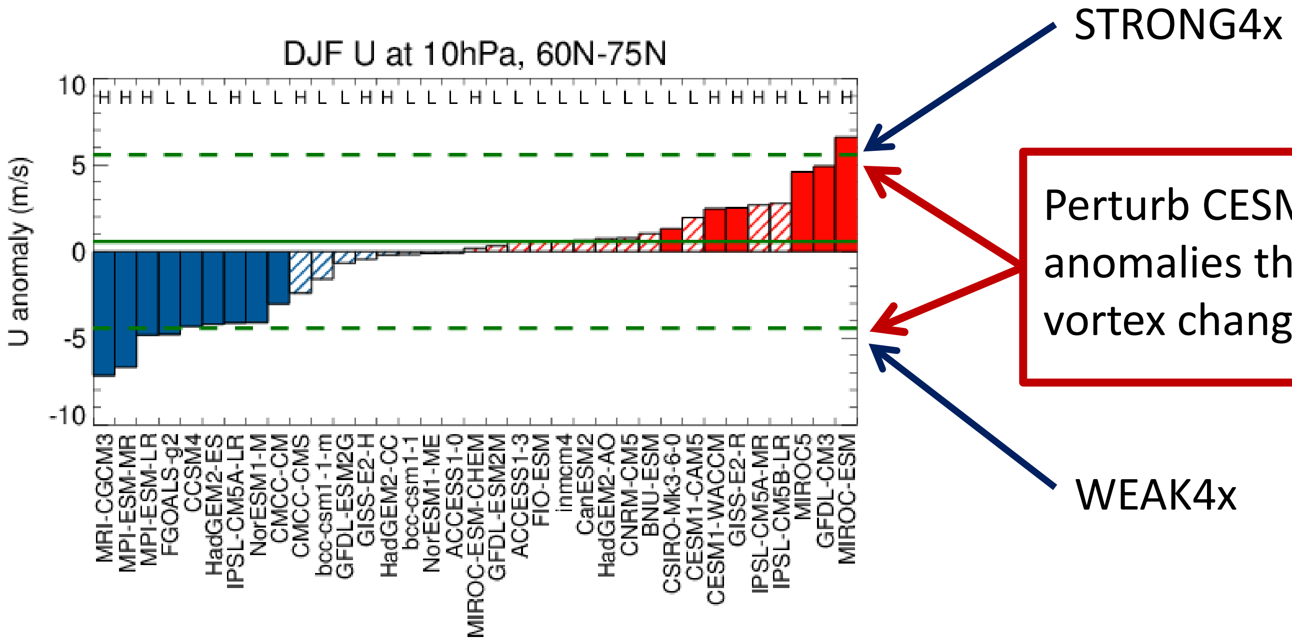


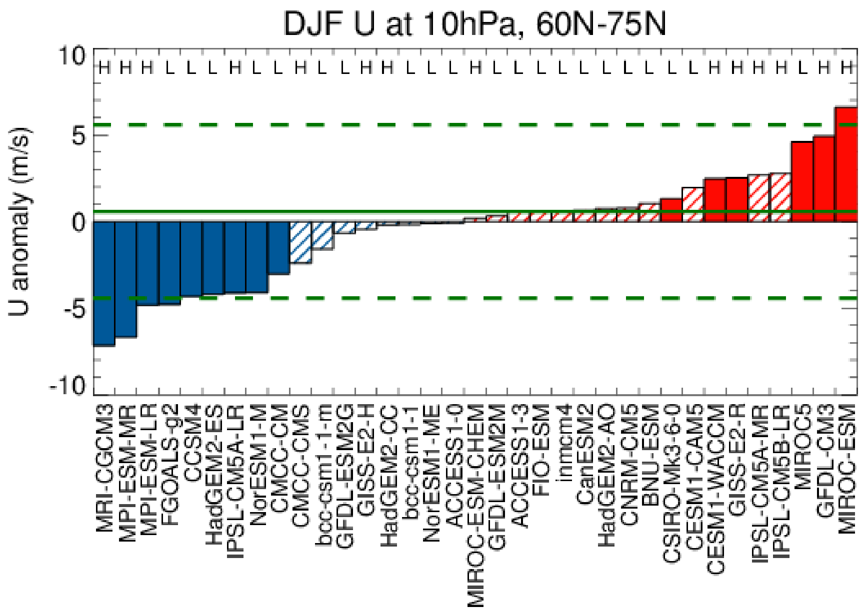
Polar vortex index of CESML46
4xCO2 – 1xCO2

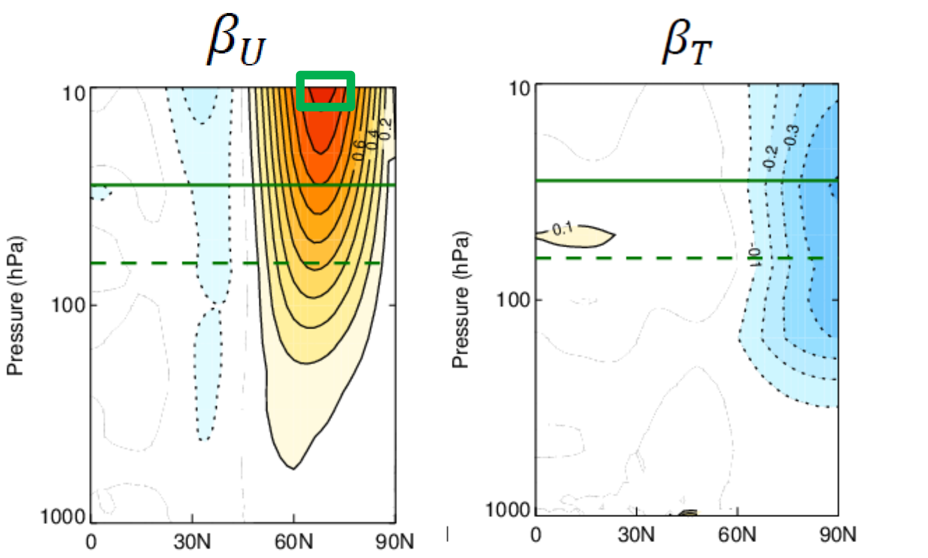
Designing the perturbations



Perturb CESM under 4xCO2 with anomalies that mimic a polar vortex change index of +/-5m/s

Designing the perturbations





Across model regressions onto the polar vortex index (DJF)

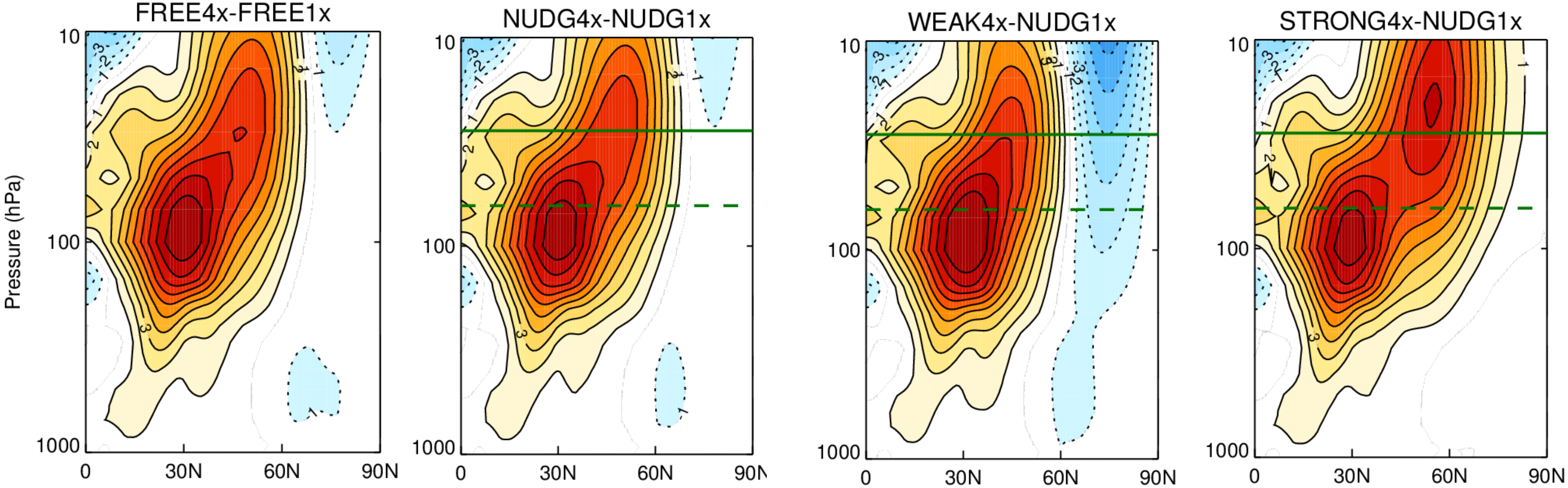
STRONG: $U,T,V = U_{4x}, T_{4x}, V_{4x} + 5 \times \beta_u, \beta_T, \beta_v$

WEAK: $U,T,V = U_{4x}, T_{4x}, V_{4x} - 5 \times \beta_u, \beta_T, \beta_v$

The Experiments

4xCO2-1xCO2 difference in zonal mean zonal wind

Free running	Nudged	Weakened vortex	Strengthened vortex
FREE4x – FREE1x	NUDG4x – NUDG1x	WEAK4x – NUDG1x	STRONG4x – NUDG1x



The Experiments

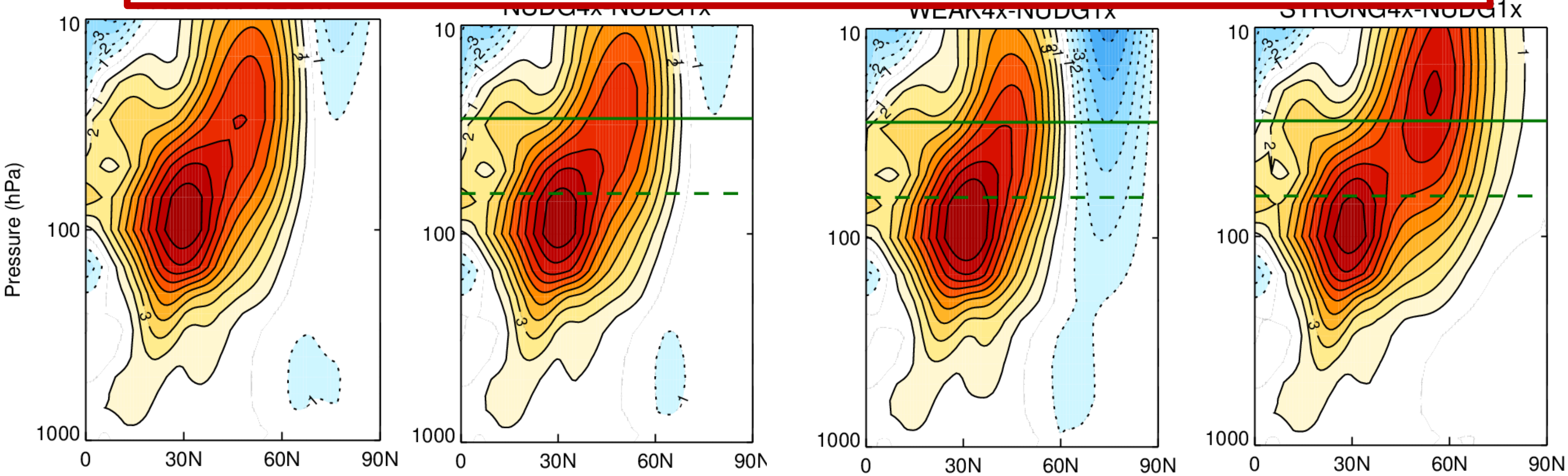
4xCO2-1xCO2 difference in zonal mean zonal wind

Fr ... ed

FR ... DG1x

CAVEAT: Since these experiments involve nudging toward a climatological state, they won't capture any non-linear influences on tropospheric circulation associated transient events such as SSW's or planetary wave reflection.

They will only capture the influence of the climatological zonal mean stratospheric boundary conditions on the troposphere below.



By construction, the difference in the stratospheric response between WEAK4x and STRONG4x is equal to the CMIP5 regression onto the polar vortex index, times 10

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WEAK4x – STRONG4x

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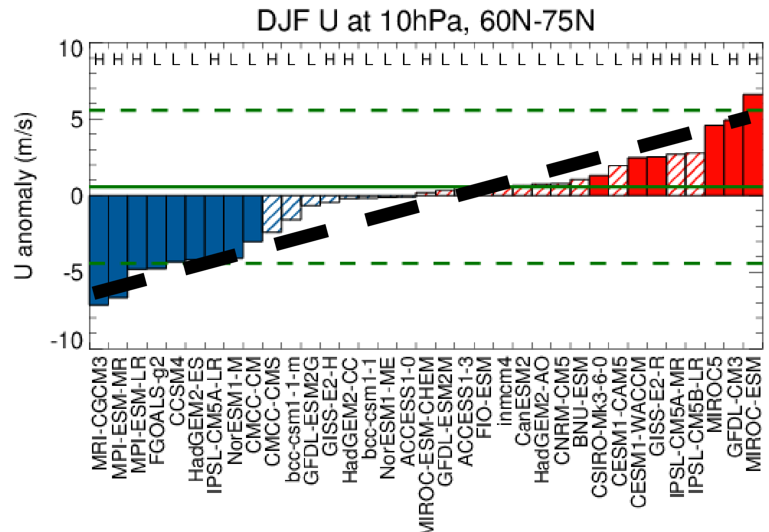
VS



Linear regression, across 35 CMIP5 models of fields onto polar vortex index (x 10) (x -1)

Similar to Manzini et al (2014)

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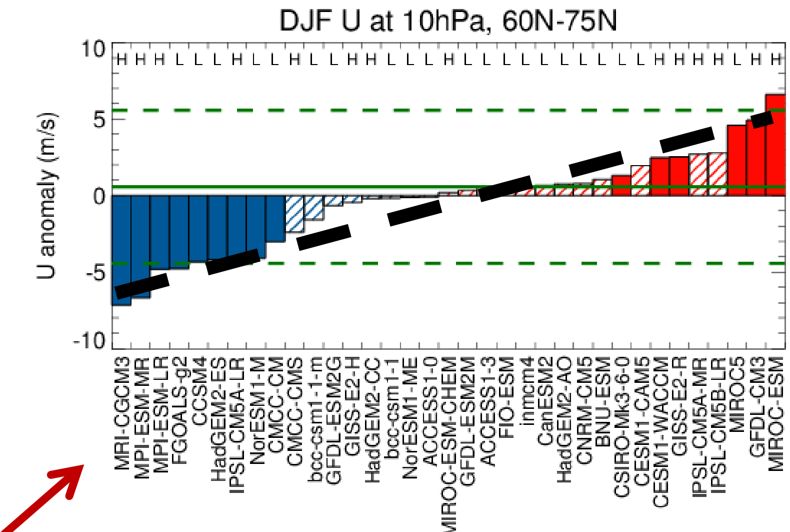


WEAK4x – STRONG4x

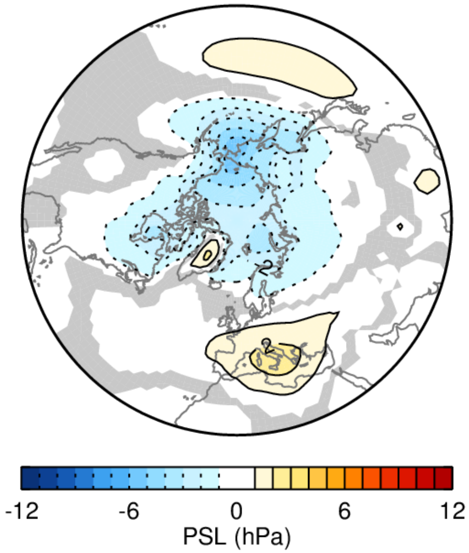
vs

Linear regression, across 35 CMIP5 models of fields onto polar vortex index (x 10) (x -1)

Similar to Manzini et al (2014)

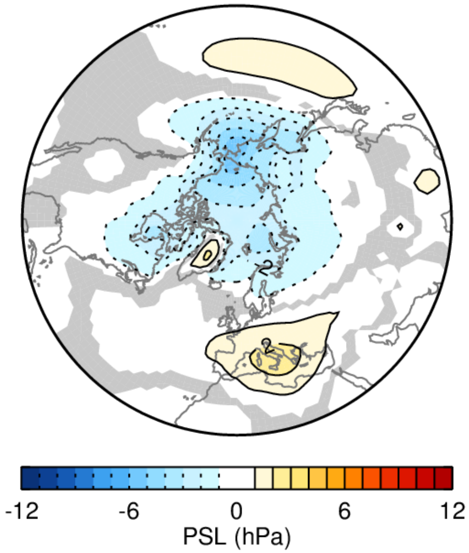
If the downward influence inferred from the across-model regression really is a downward influence of the climatological stratospheric circulation change on the troposphere below, then we should see the same influence in our idealized CESM experiments.

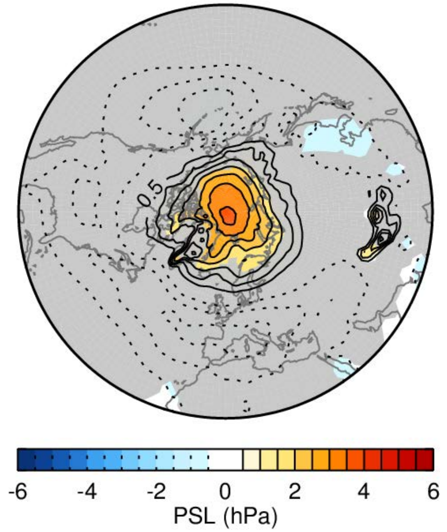
Sea Level Pressure



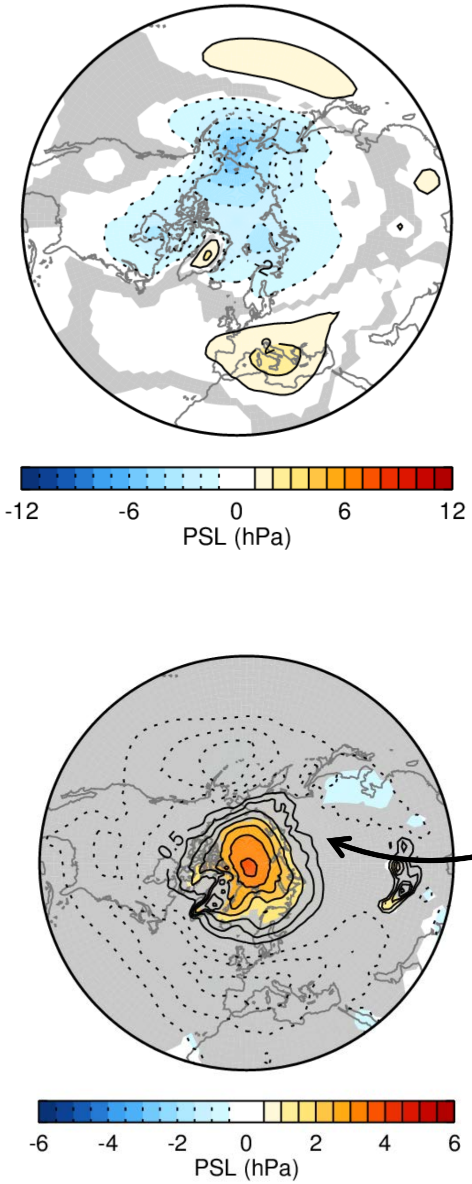
CMIP5 multi-model mean
Future - Past

Grey = not significantly different from zero at the 95% level





CMIP5 regression onto Polar Vortex (x-10)



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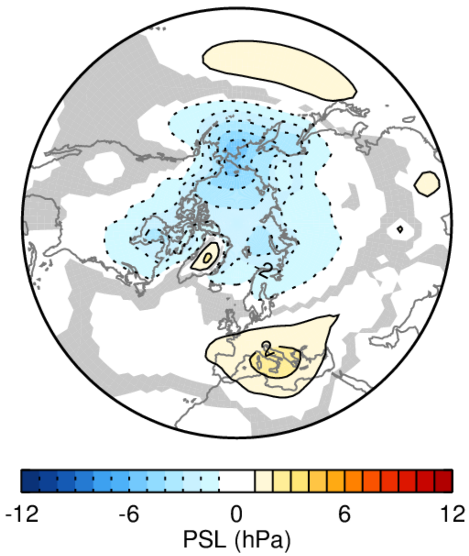
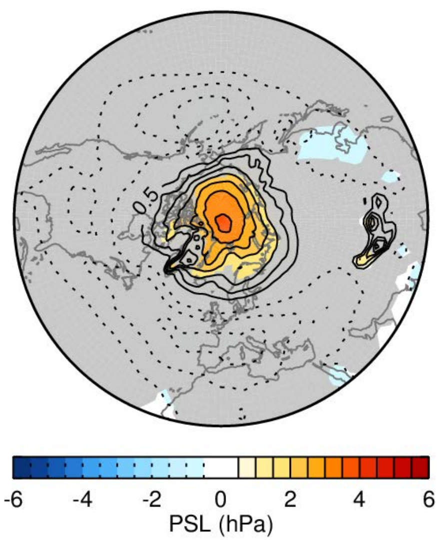
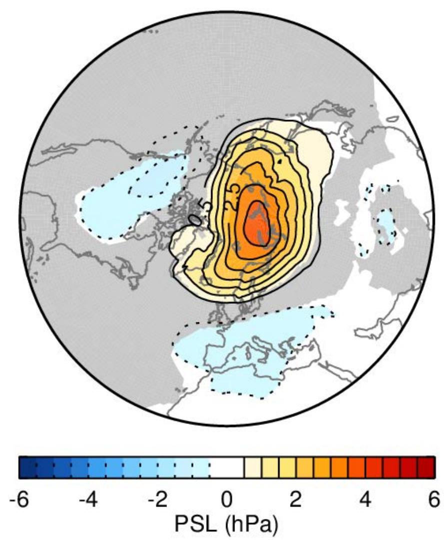
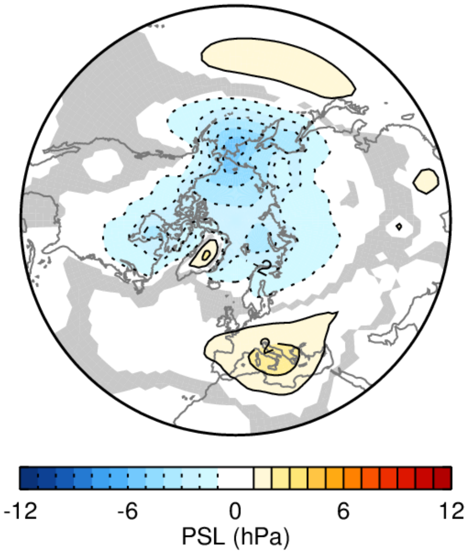
CMIP5 regression onto Polar Vortex (x-10)



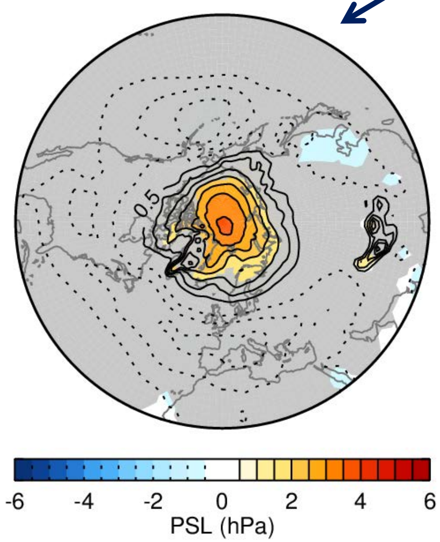


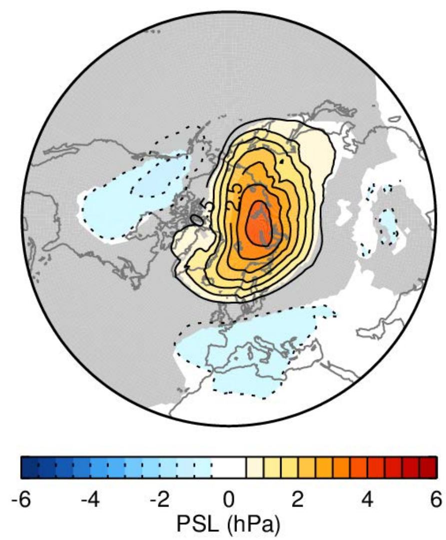


WEAK4x-STRONG4x



These mostly agree within the uncertainties





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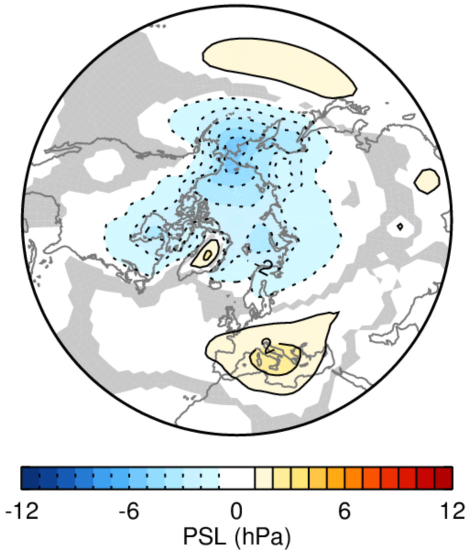
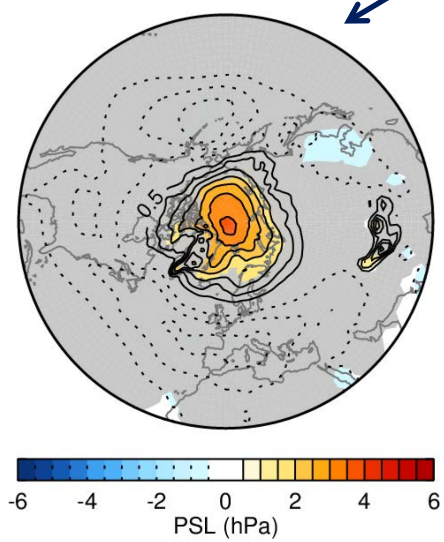
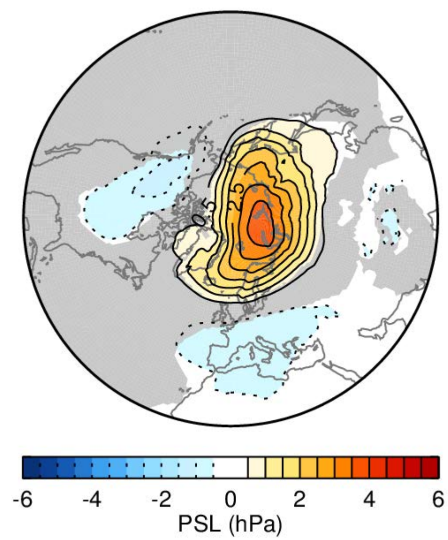


These mostly agree within the uncertainties

The SLP anomalies found in the CMIP5 regression can be thought of as a response to the different stratospheric vortex changes





WEAK4x-STRONG4x

How big is this stratospheric influence relative to the CMIP5 model spread?

Two measures:

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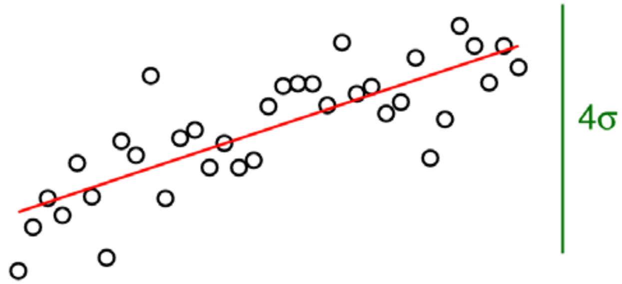

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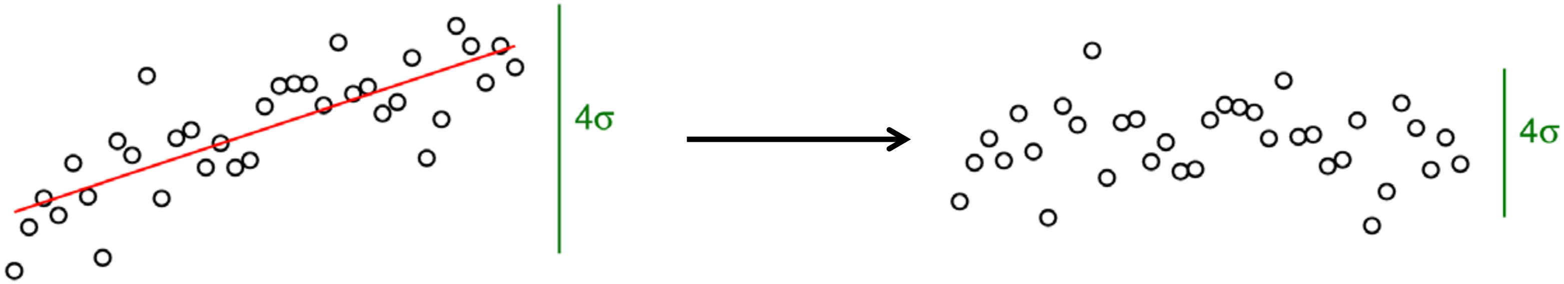

(Note that Manzini et al 2014 did something similar but with a different set of models and different methodology)

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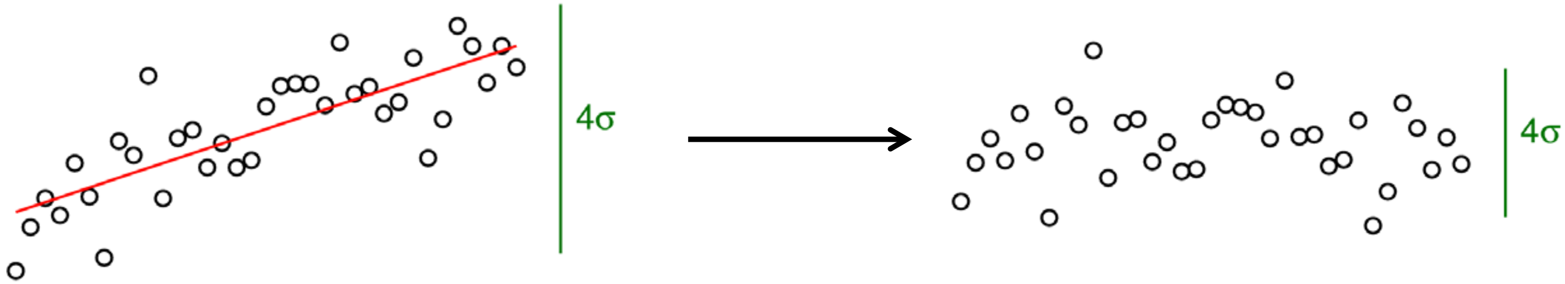


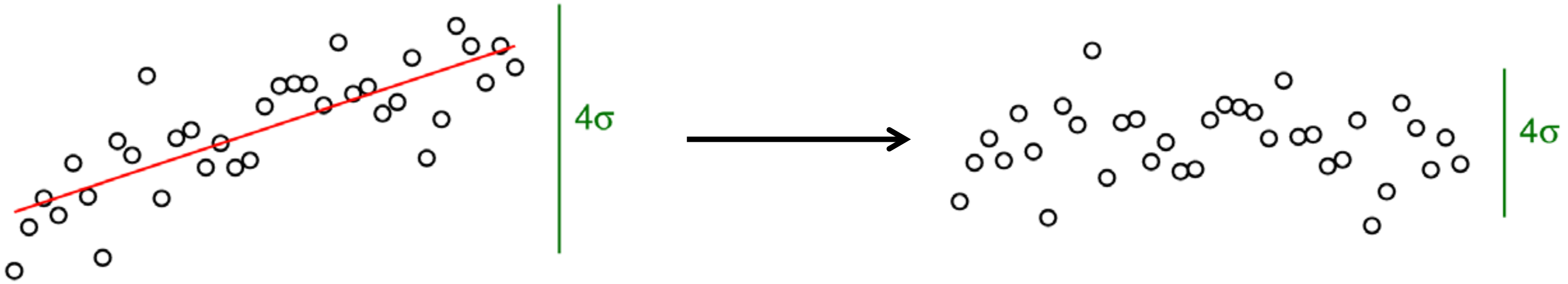
(Note that Manzini et al 2014 did something similar but with a different set of models and different methodology)

- How big is the difference between models on the extreme end of the scale compared to the CMIP5 range?

How big is this stratospheric influence relative to the CMIP5 model spread?

Two measures:

- How much is the CMIP5 spread reduced by regressing out the stratospheric influence?

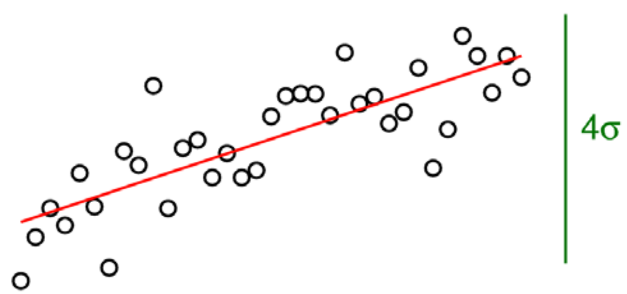


(Note that Manzini et al 2014 did something similar but with a different set of models and different methodology)

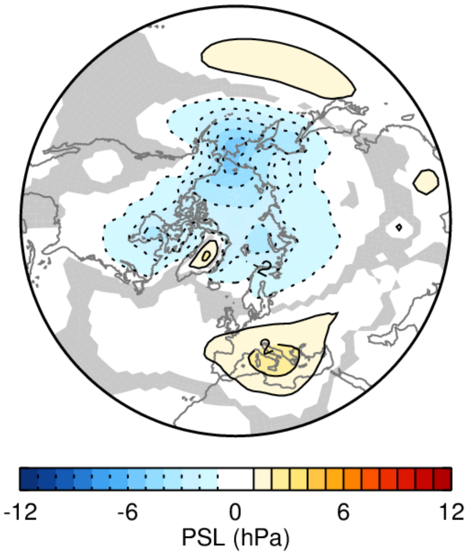
- How big is the difference between models on the extreme end of the scale compared to the CMIP5 range?

WEAK - STRONG

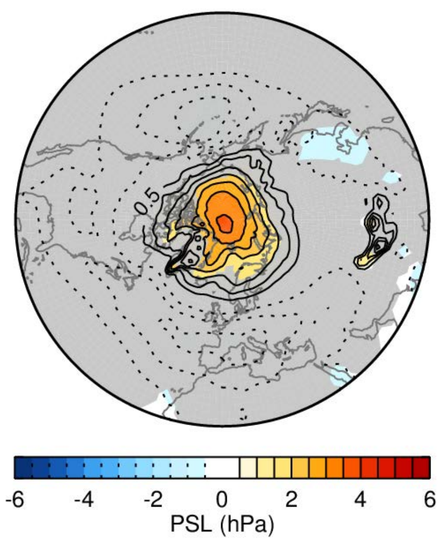
vs



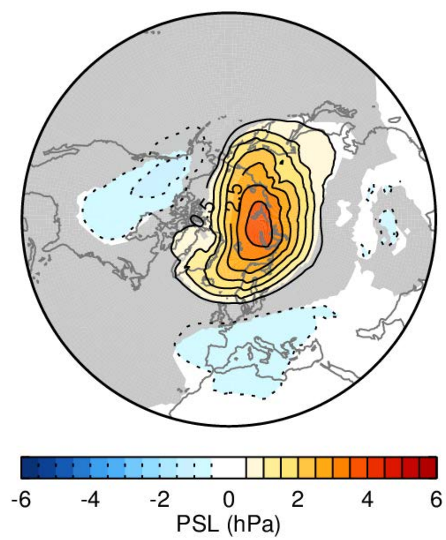
Future-Past, multi-model mean



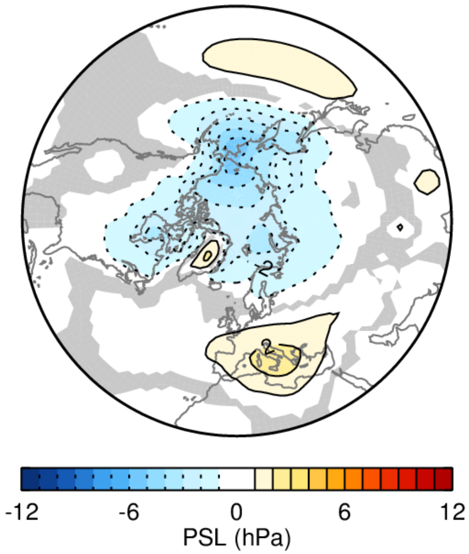
Regression onto Polar Vortex index



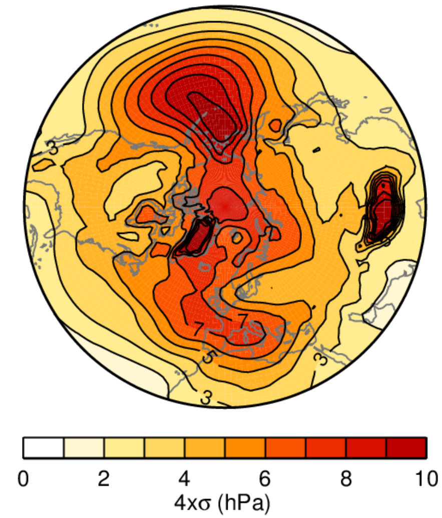
WEAK4x-STRONG4x



Future-Past, multi-model mean

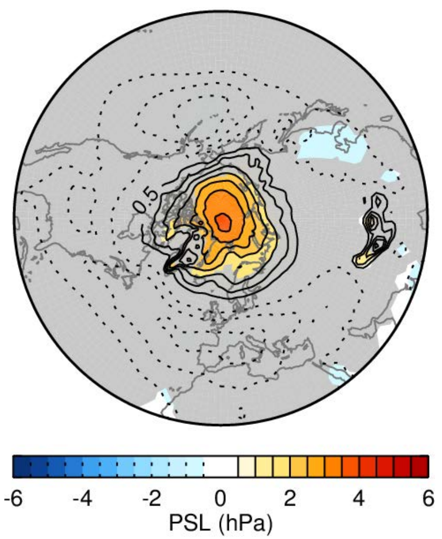


CMIP5 spread

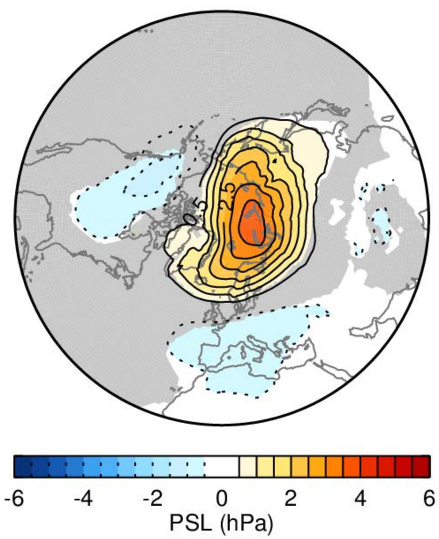


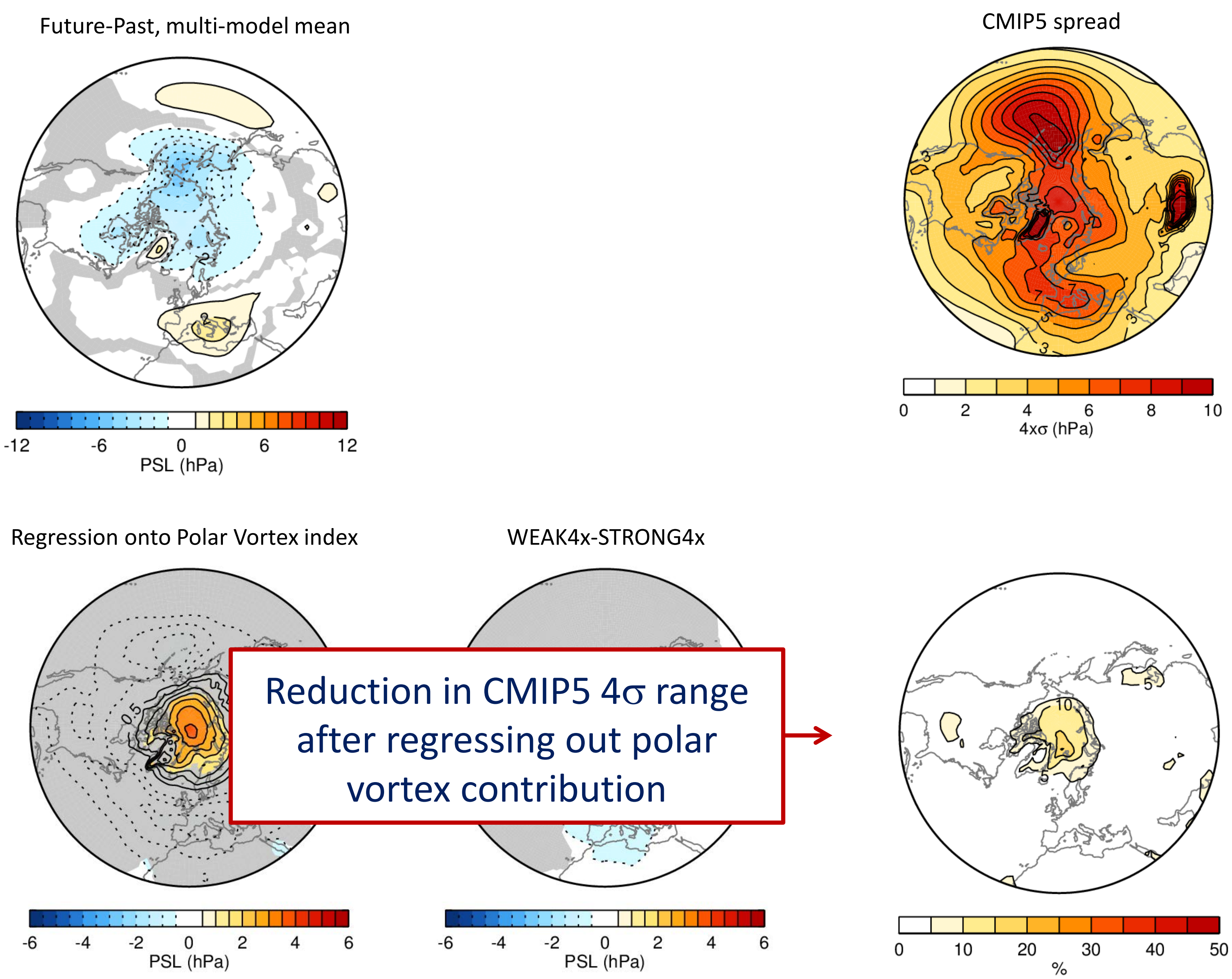
CMIP5 4σ range

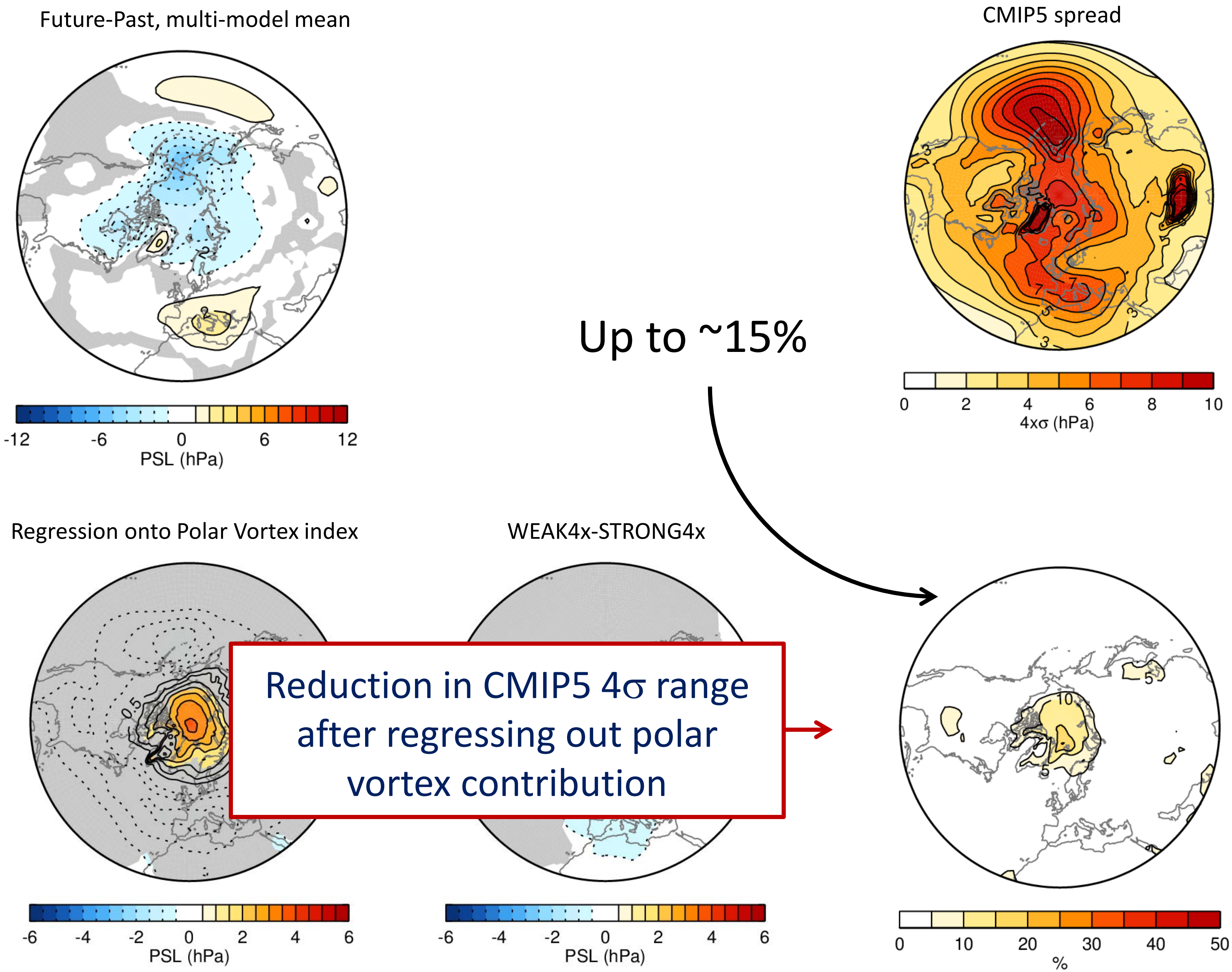
Regression onto Polar Vortex index



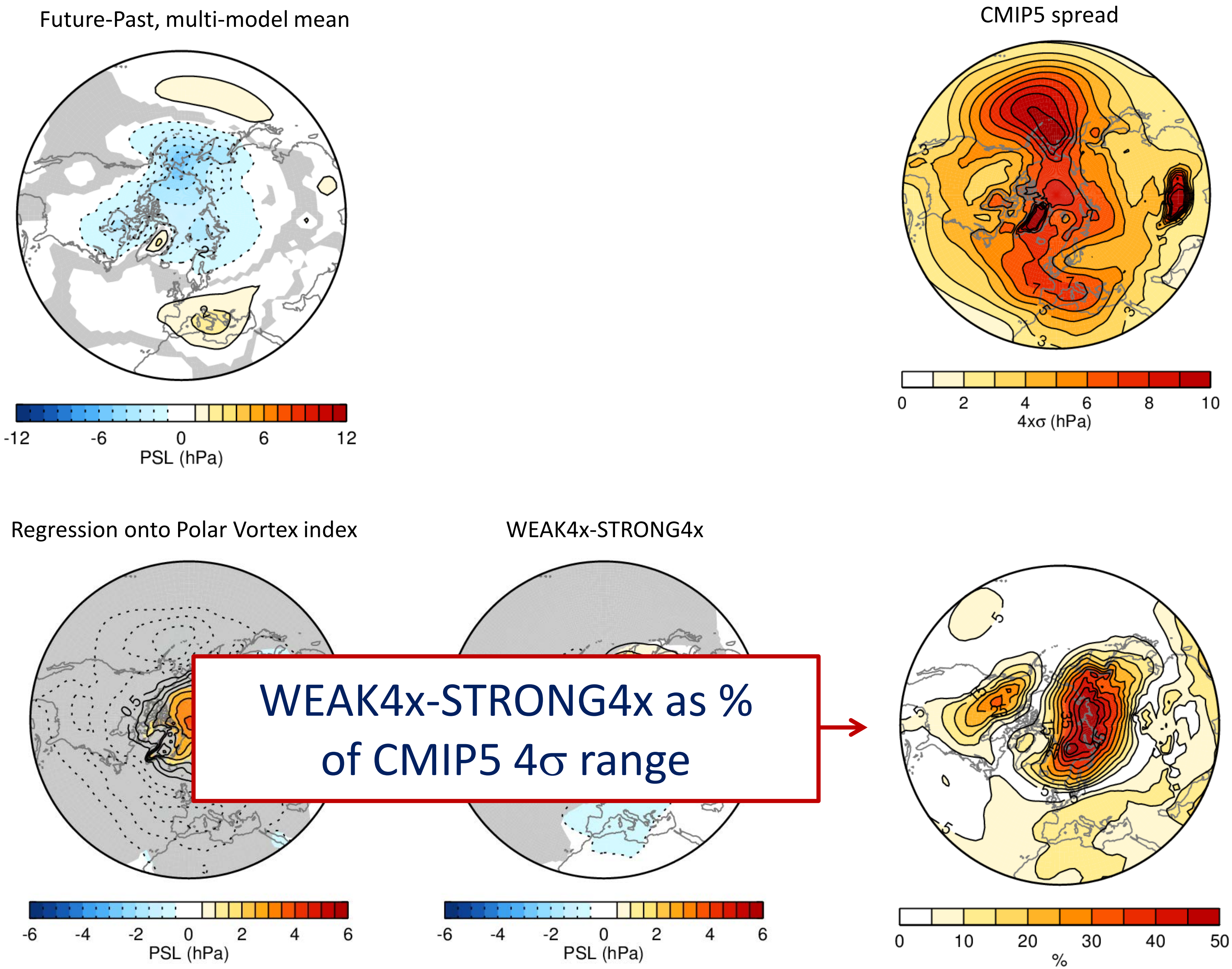
WEAK4x-STRONG4x



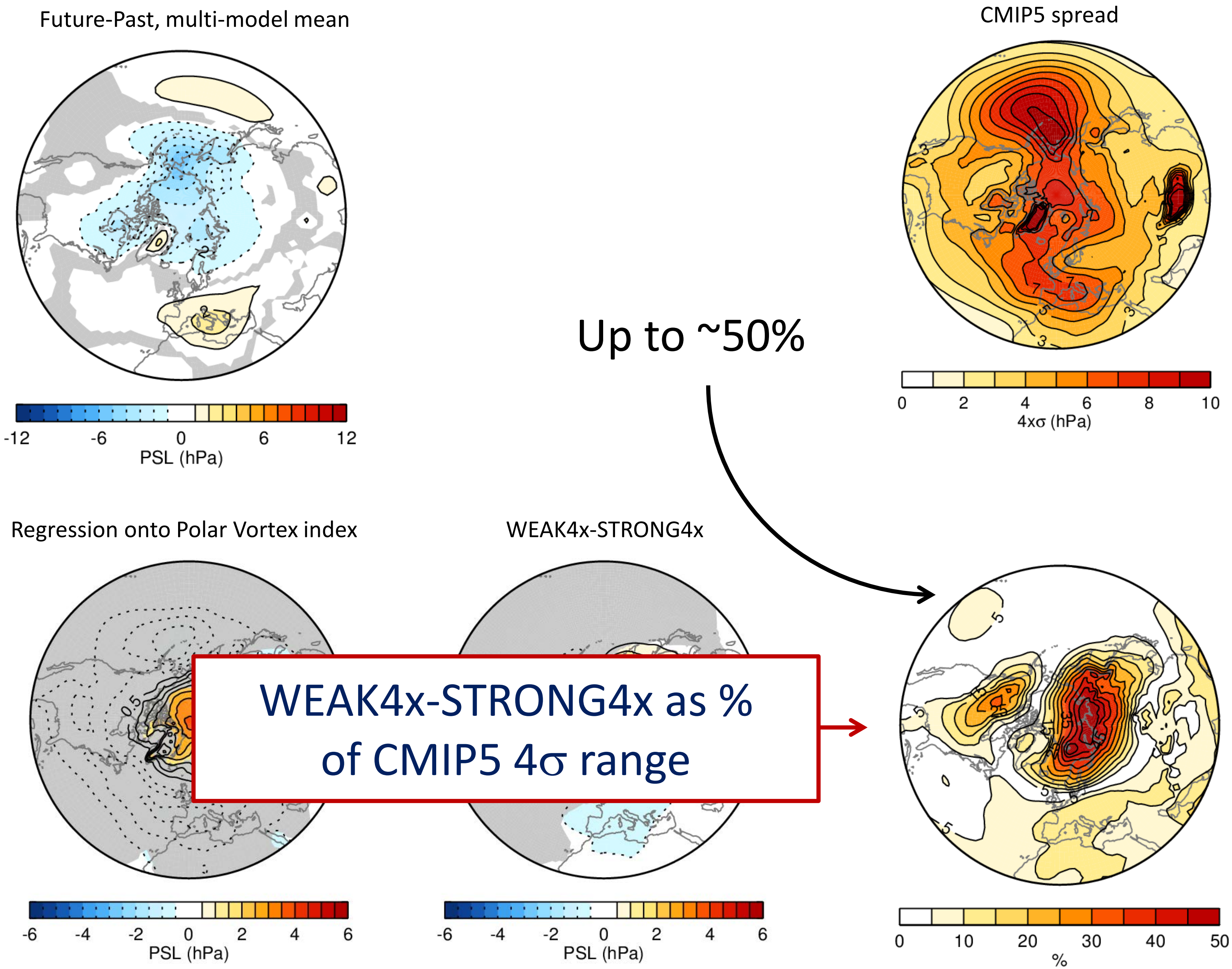

Future-Past, multi-model mean
-12
-6
0
6
12
PSL (hPa)
CMIP5 spread
0
2
4
6
8
10
4xσ (hPa)
Regression onto Polar Vortex index
-6
-4
-2
0
2
4
6
PSL (hPa)
WEAK4x-STRONG4x
-6
-4
-2
0
2
4
6
PSL (hPa)
Reduction in CMIP5 4σ range after regressing out polar vortex contribution
0
10
20
30
40
50
%



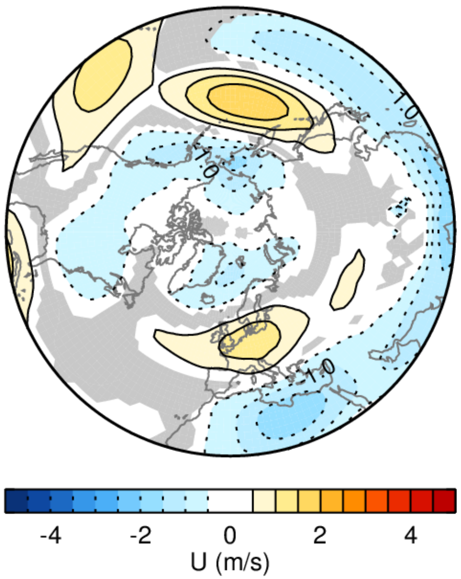
Future-Past, multi-model mean
-12
-6
0
6
12
PSL (hPa)
CMIP5 spread
0
2
4
6
8
10
4xσ (hPa)
Up to ~15%
Regression onto Polar Vortex index
-6
-4
-2
0
2
4
6
PSL (hPa)
WEAK4x-STRONG4x
-6
-4
-2
0
2
4
6
PSL (hPa)
Reduction in CMIP5 4σ range after regressing out polar vortex contribution
0
10
20
30
40
50
%



Future-Past, multi-model mean
-12
-6
0
6
12
PSL (hPa)
CMIP5 spread
0
2
4
6
8
10
4xσ (hPa)
Regression onto Polar Vortex index
-6
-4
-2
0
2
4
6
PSL (hPa)
WEAK4x-STRONG4x
-6
-4
-2
0
2
4
6
PSL (hPa)
WEAK4x-STRONG4x as % of CMIP5 4σ range
0
10
20
30
40
50
%

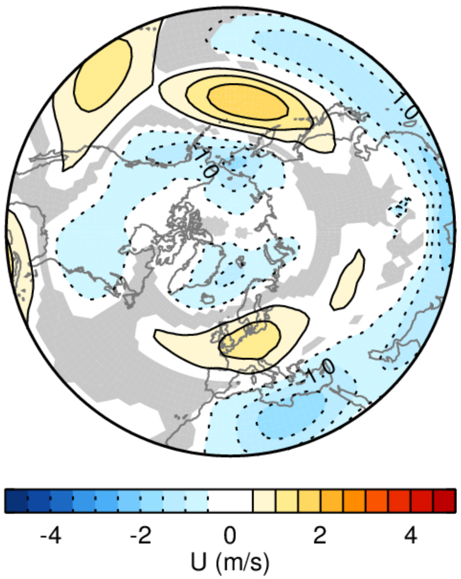

Future-Past, multi-model mean
-12 -6 0 6 12
PSL (hPa)
CMIP5 spread
0 2 4 6 8 10
4xσ (hPa)
Up to ~50%
Regression onto Polar Vortex index
-6 -4 -2 0 2 4 6
PSL (hPa)
WEAK4x-STRONG4x
-6 -4 -2 0 2 4 6
PSL (hPa)
WEAK4x-STRONG4x as % of CMIP5 4σ range
0 10 20 30 40 50
%

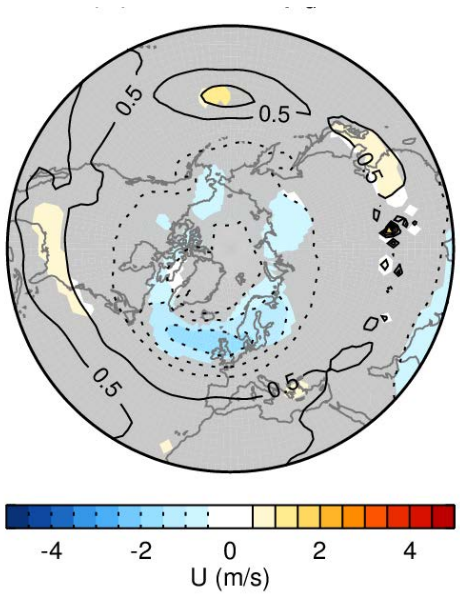
700hPa zonal wind



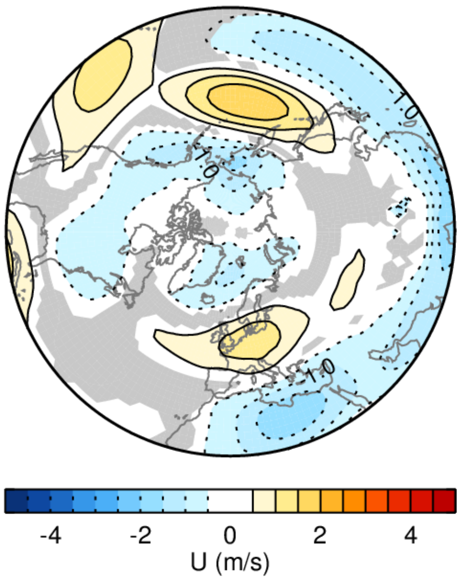
CMIP5 multi-model mean
Future - Past

Grey = not significantly different from zero at the 95% level

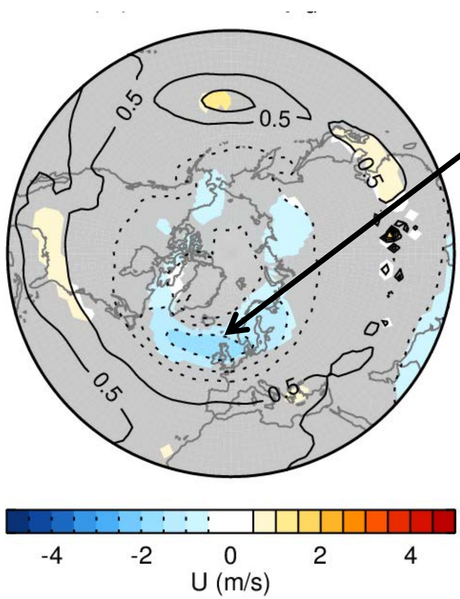




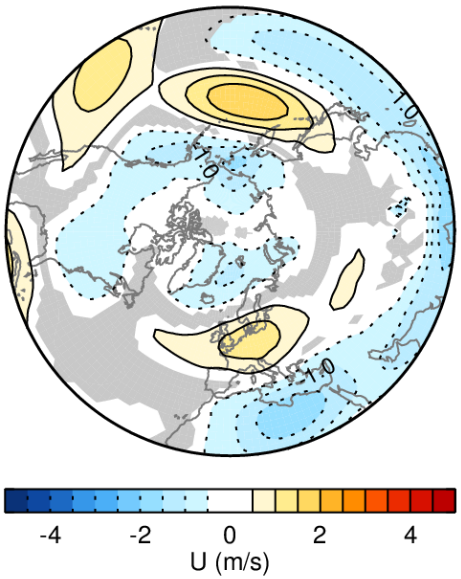
CMIP5 regression onto Polar Vortex (x-10)

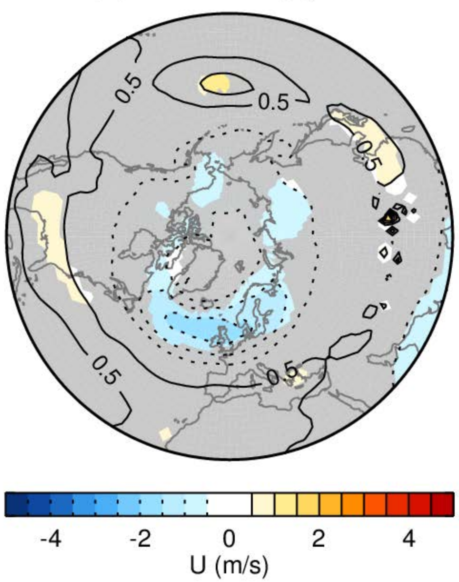


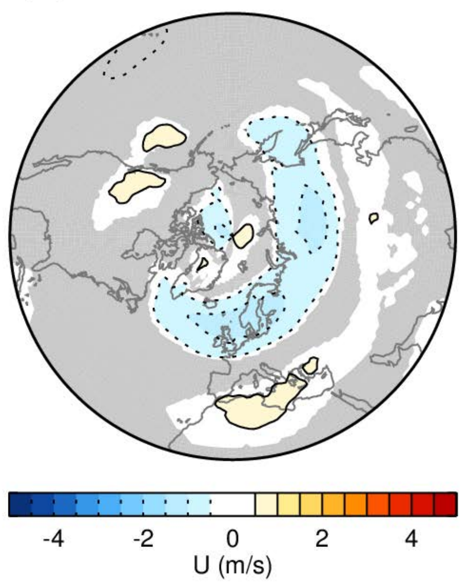
With a relative weakening of the polar vortex comes a reduced zonal wind localized over the North Atlantic/Europe



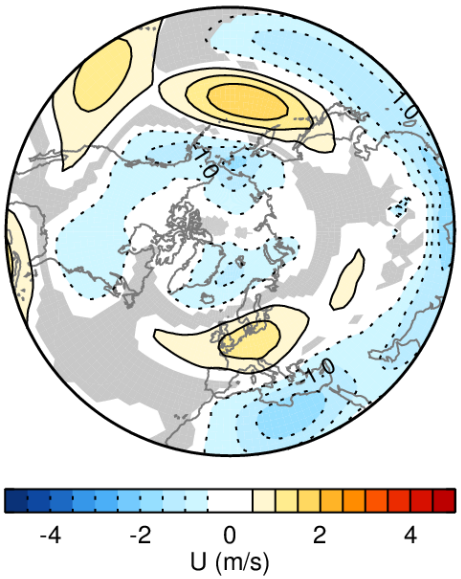
CMIP5 regression onto Polar Vortex (x-10)



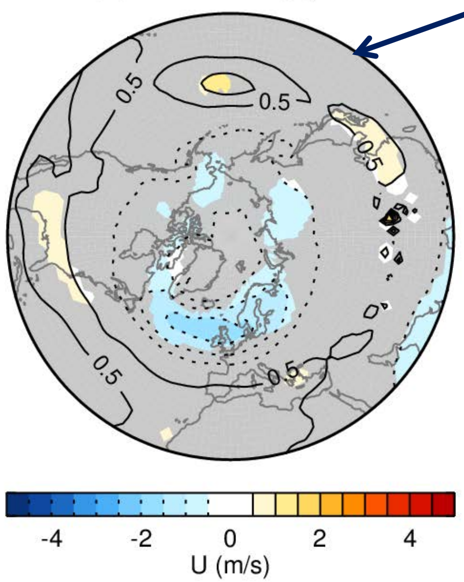


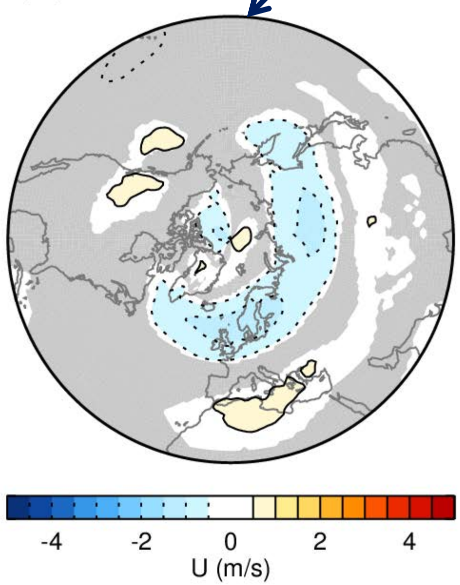


WEAK4x-STRONG4x

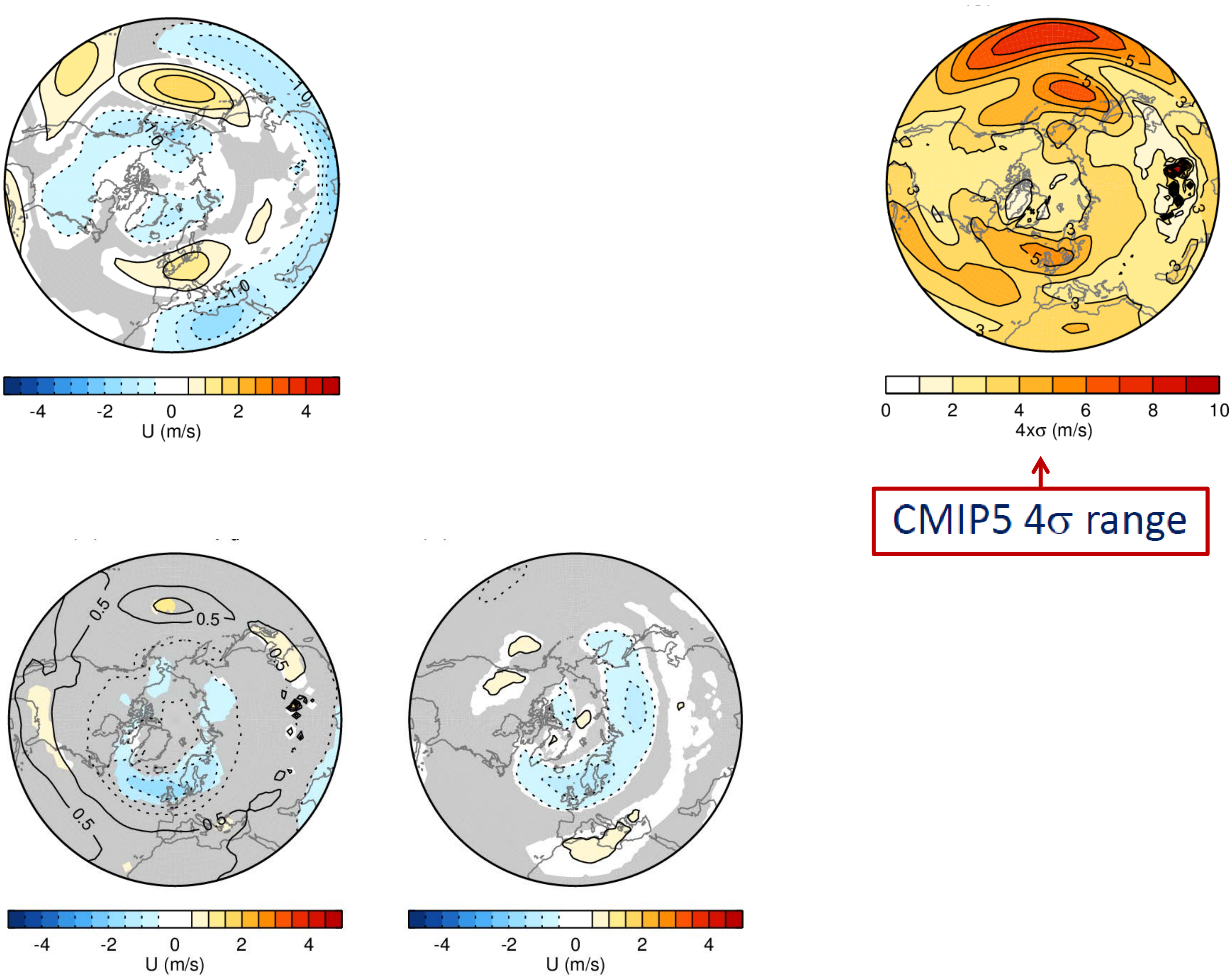


These mostly agree within the uncertainties

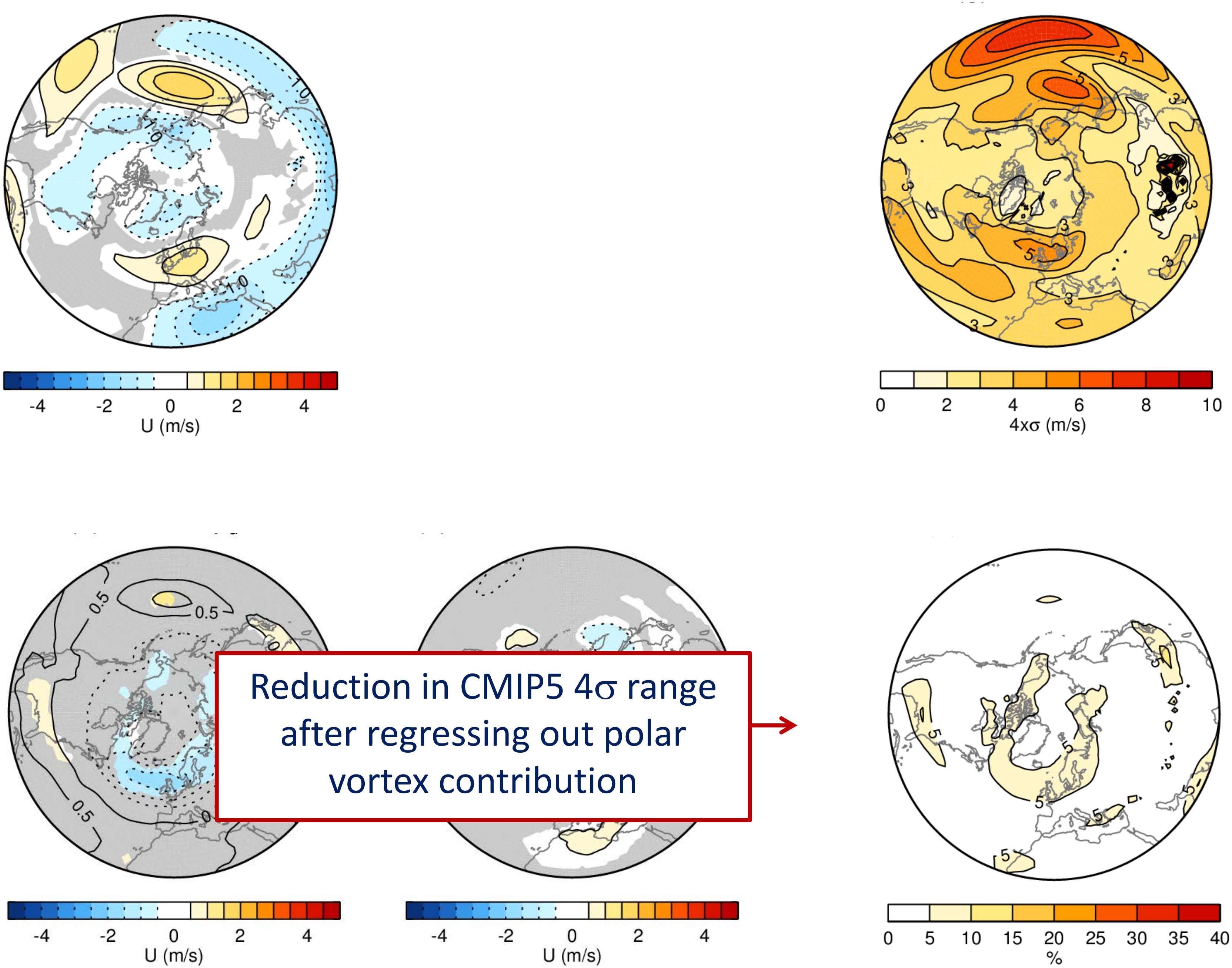




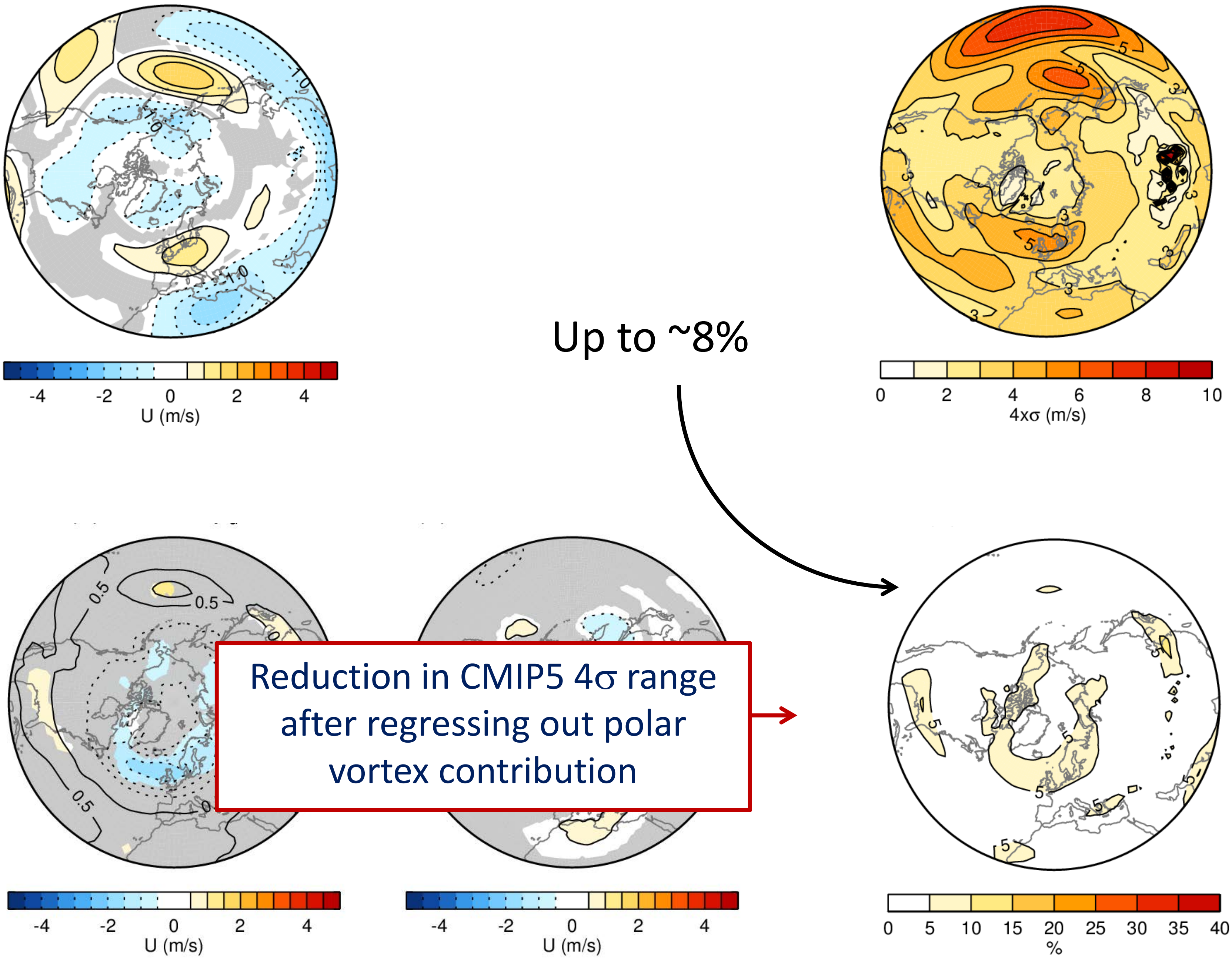
WEAK4x-STRONG4x



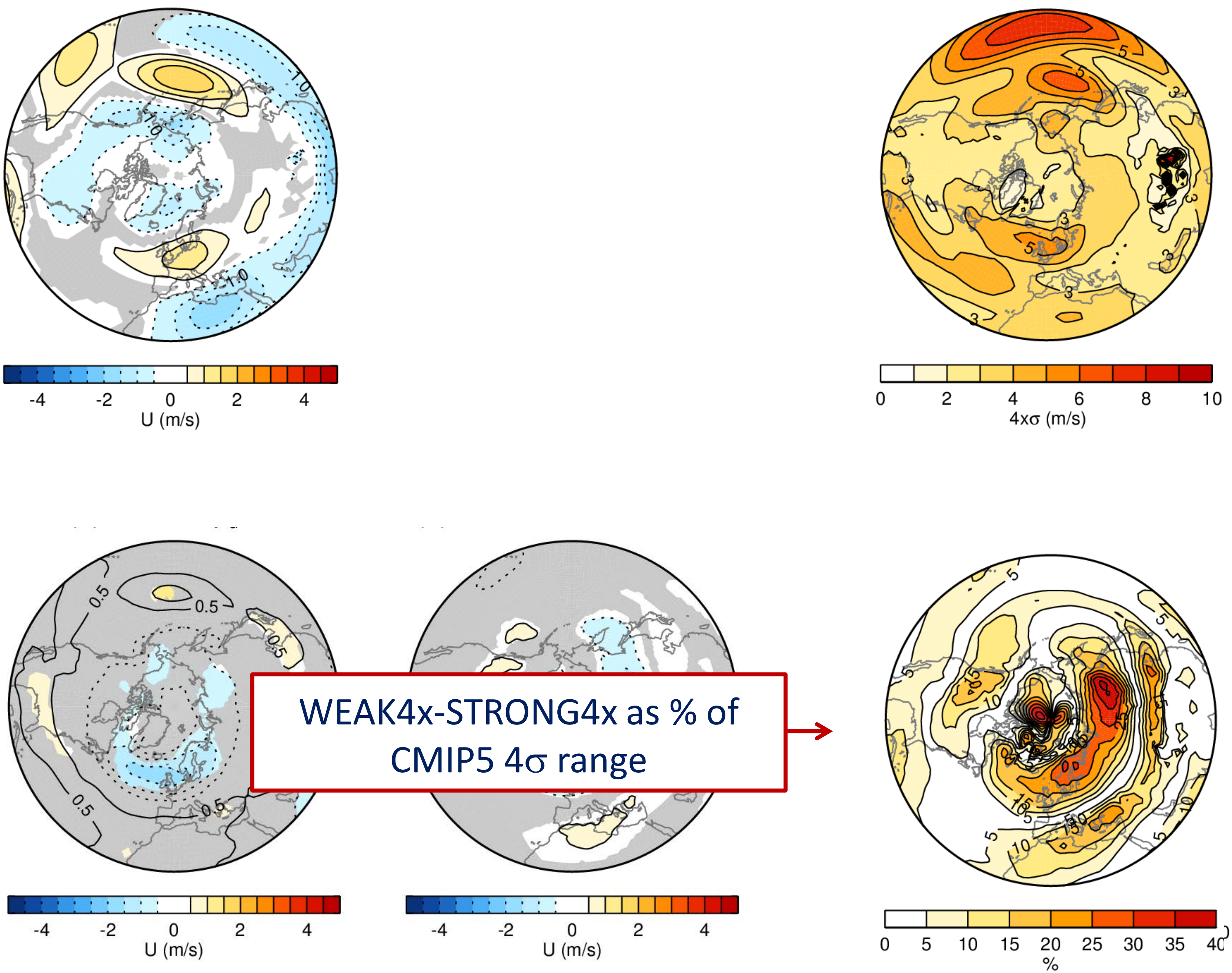
-4 -2 0 2 4
U (m/s)
0 2 4 6 8 10
4xσ (m/s)
CMIP5 4σ range
-4 -2 0 2 4
U (m/s)
-4 -2 0 2 4
U (m/s)



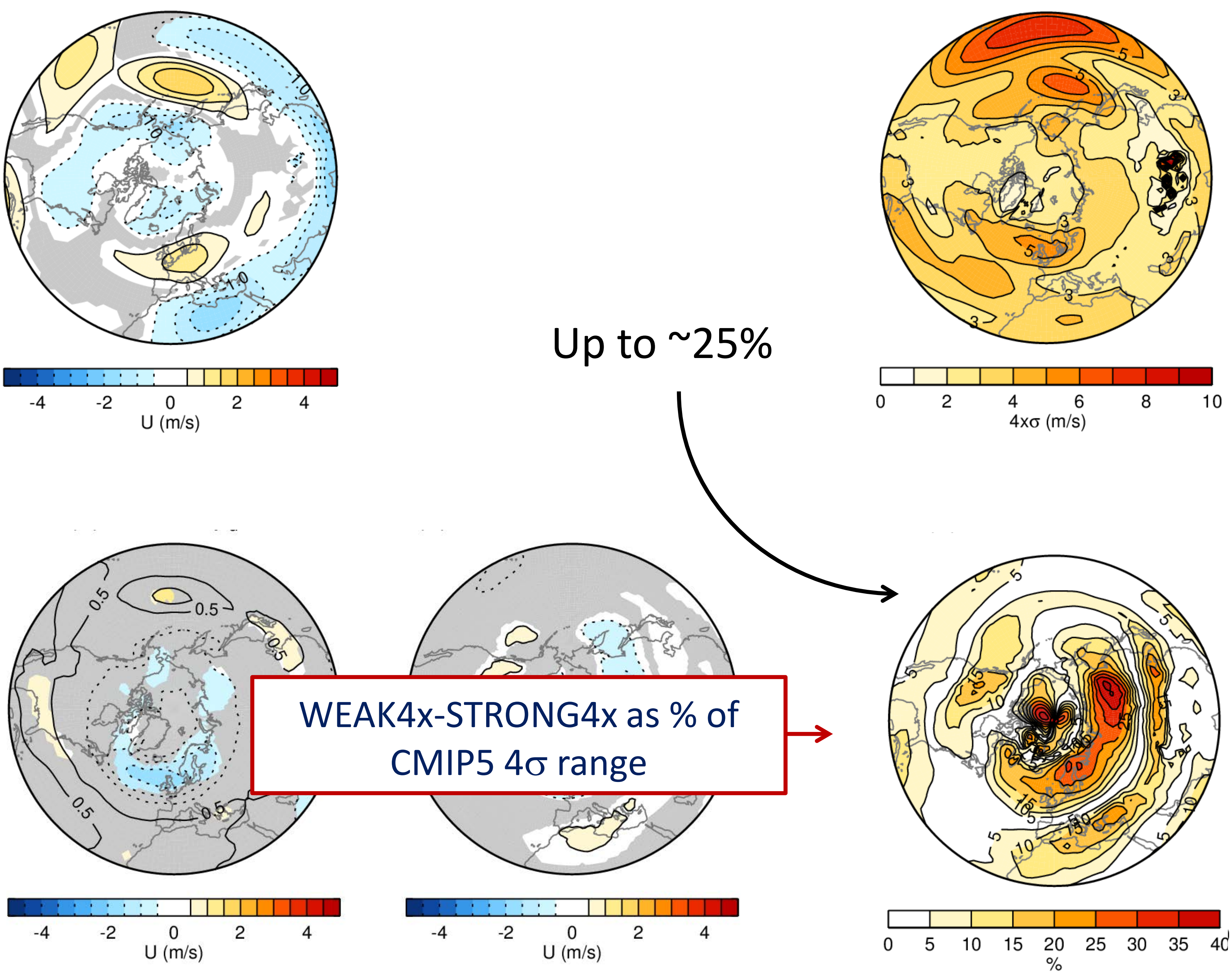
Reduction in CMIP5 4σ range after regressing out polar vortex contribution



Up to ~8%
Reduction in CMIP5 4σ range after regressing out polar vortex contribution
U (m/s)
4xσ (m/s)
U (m/s)
U (m/s)
%

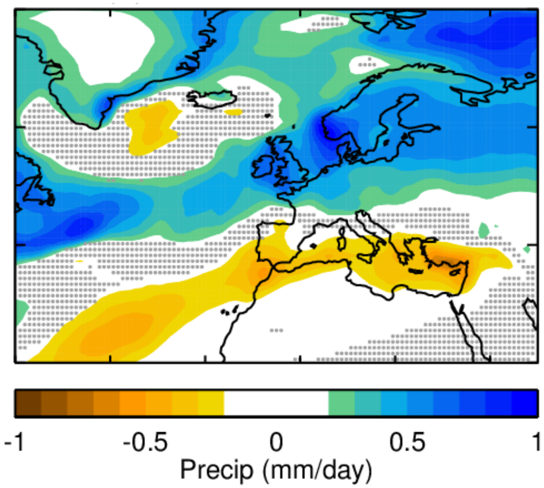


-4 -2 0 2 4
U (m/s)
0 2 4 6 8 10
4xσ (m/s)
-4 -2 0 2 4
U (m/s)
-4 -2 0 2 4
U (m/s)
WEAK4x-STRONG4x as % of CMIP5 4σ range
0 5 10 15 20 25 30 35 40
%



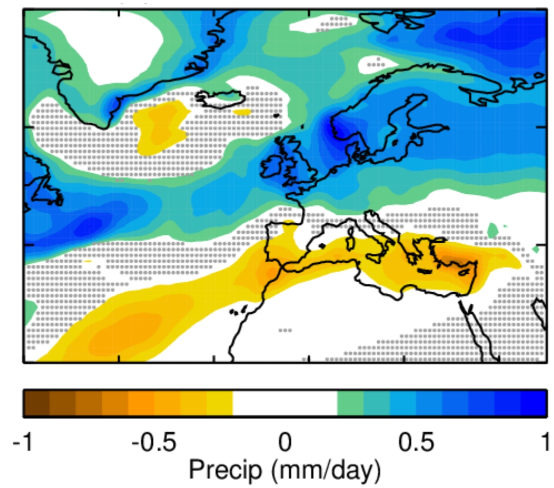
-4 -2 0 2 4
U (m/s)
Up to ~25%
0 2 4 6 8 10
4xσ (m/s)
WEAK4x-STRONG4x as % of CMIP5 4σ range
-4 -2 0 2 4
U (m/s)
-4 -2 0 2 4
U (m/s)
0 5 10 15 20 25 30 35 40
%

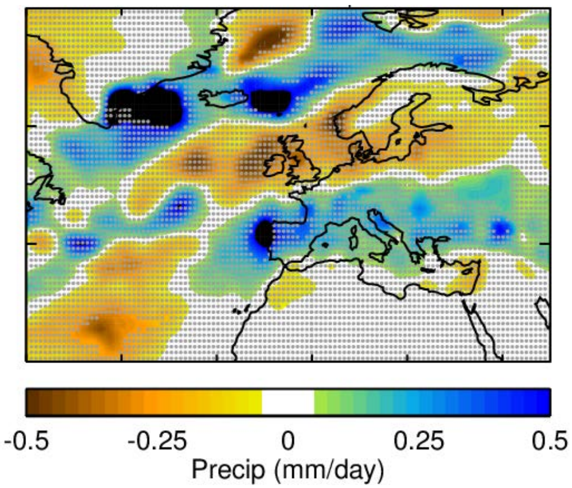
Precipitation



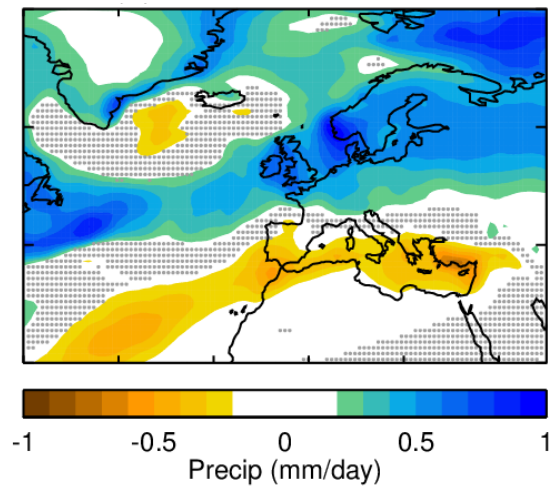
CMIP5 multi-model mean
Future - Past

Stippling = not significantly different from zero at the 95% level

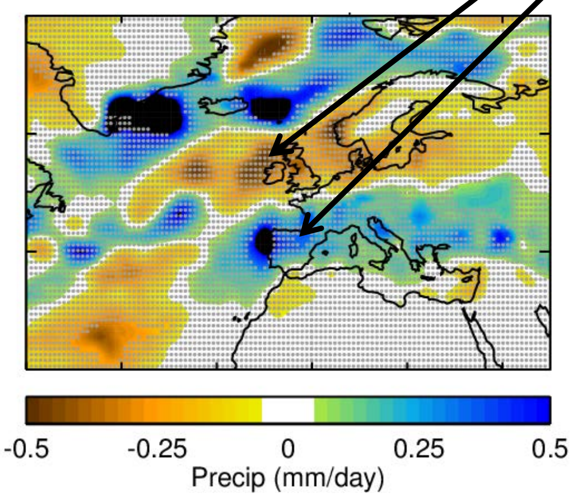




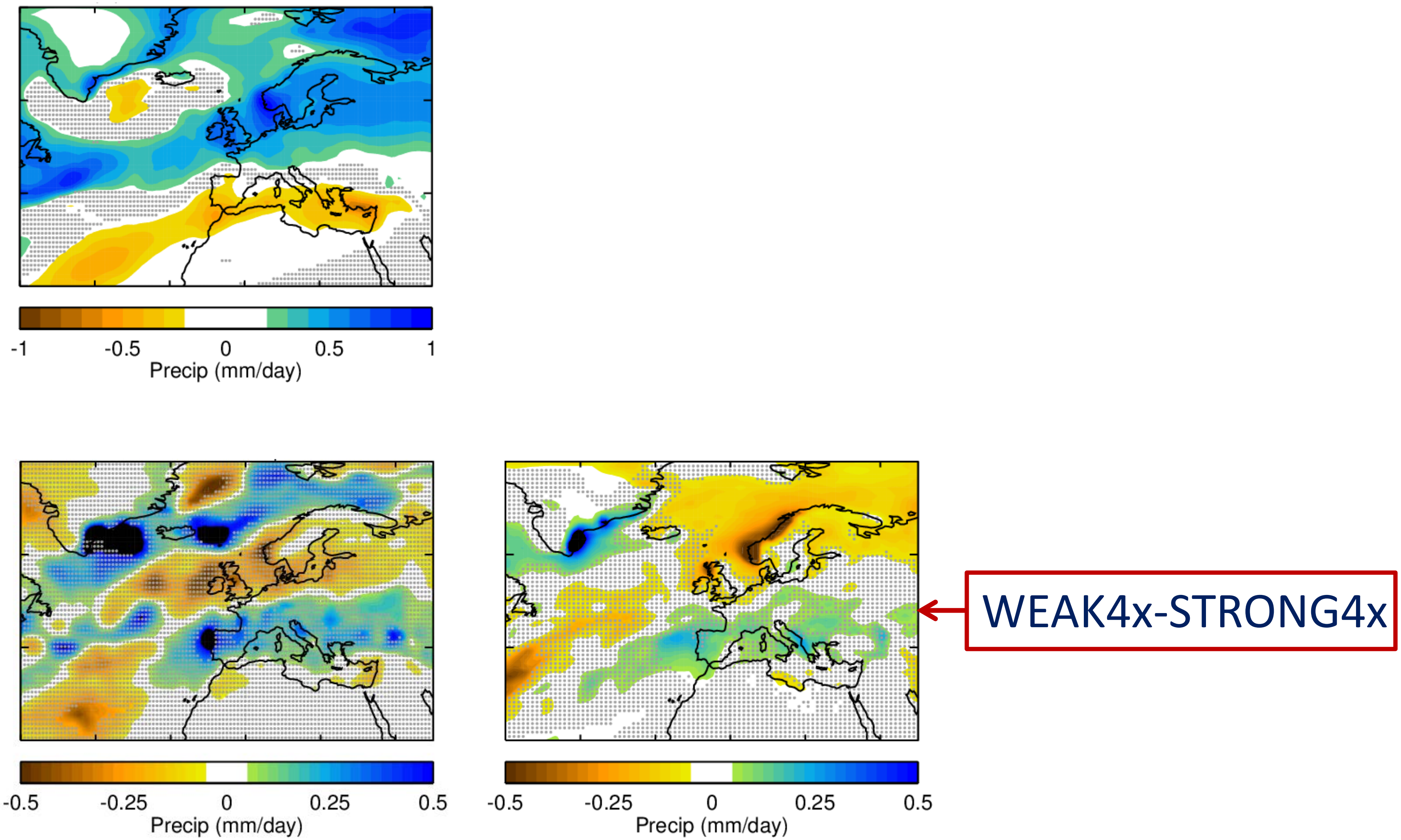
CMIP5 regression onto Polar Vortex (x-10)

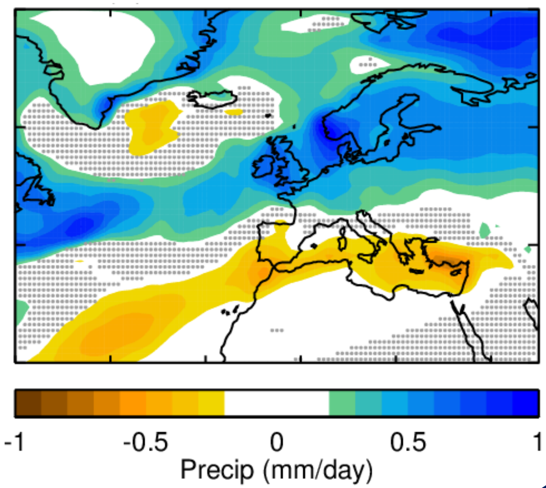


With a relative weakening of the polar vortex comes a relative decrease in precip over Northern Europe and an increase over Southern Europe

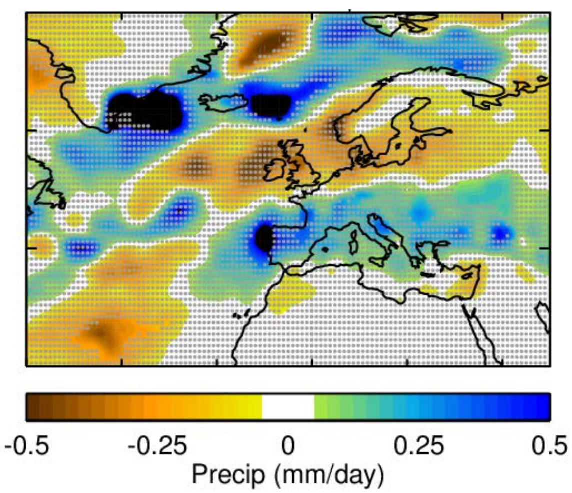


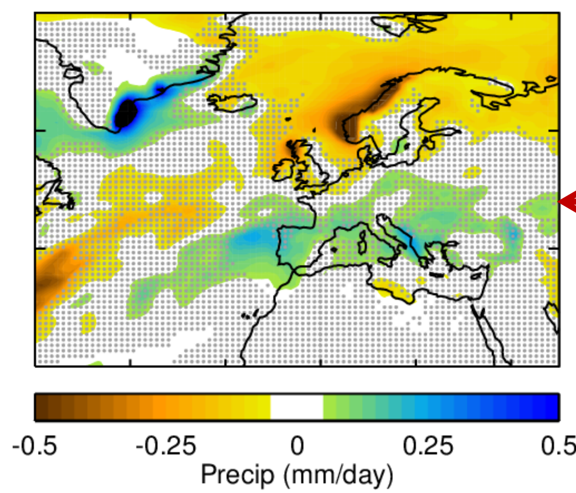
CMIP5 regression onto Polar Vortex (x-10)


-1
-0.5
0
0.5
1
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
WEAK4x-STRONG4x

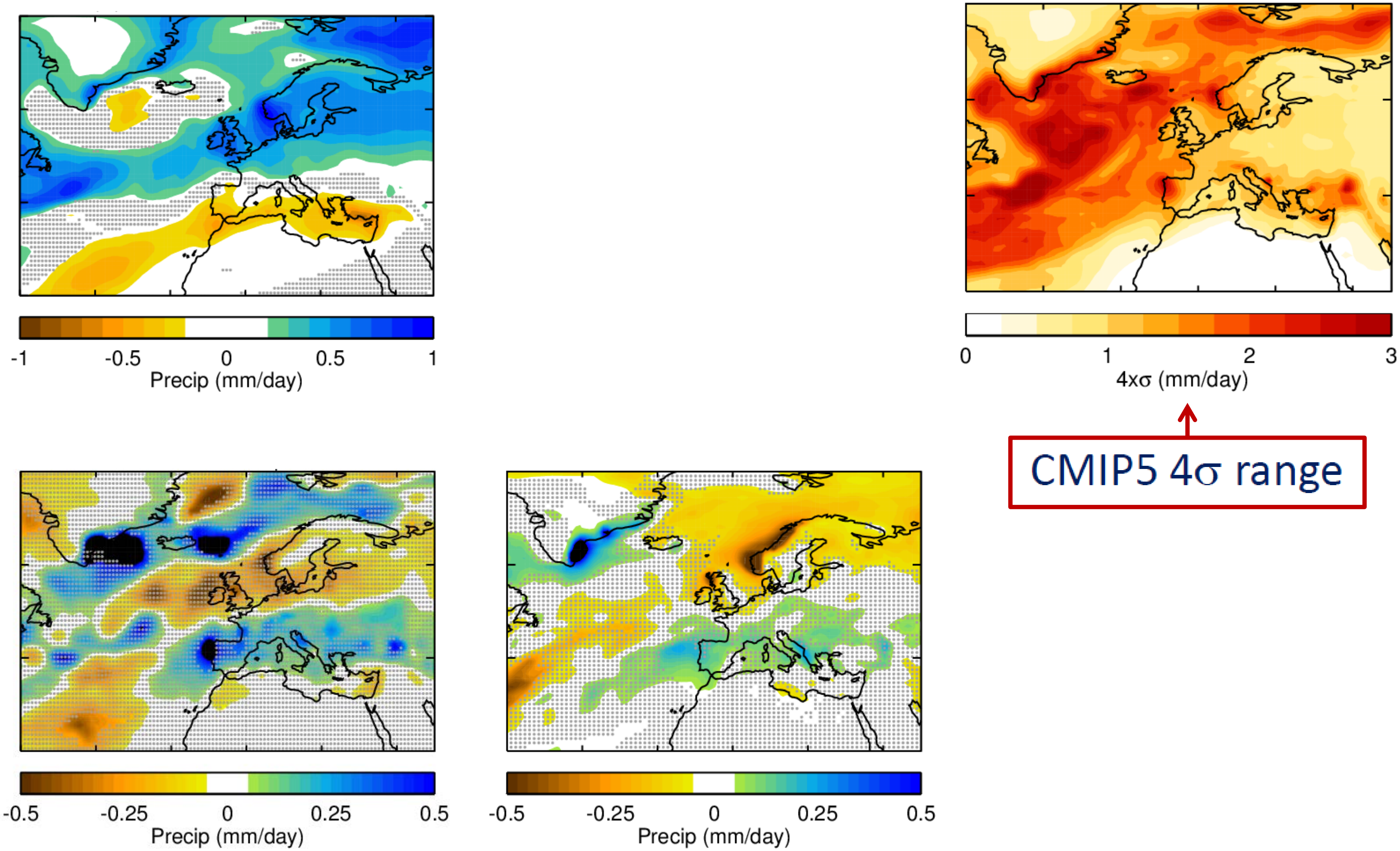


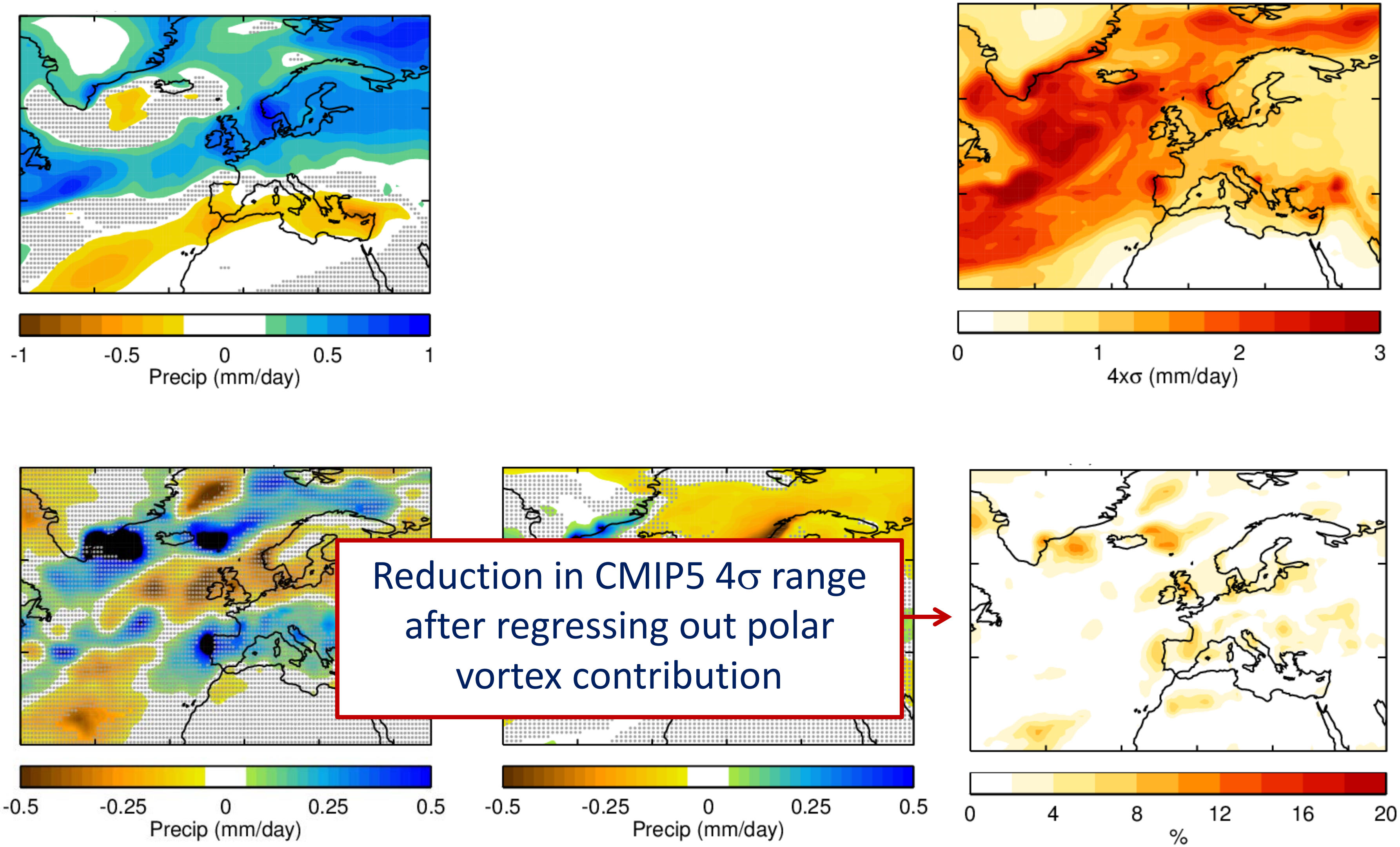
These mostly agree within the uncertainties (except east of Iceland)



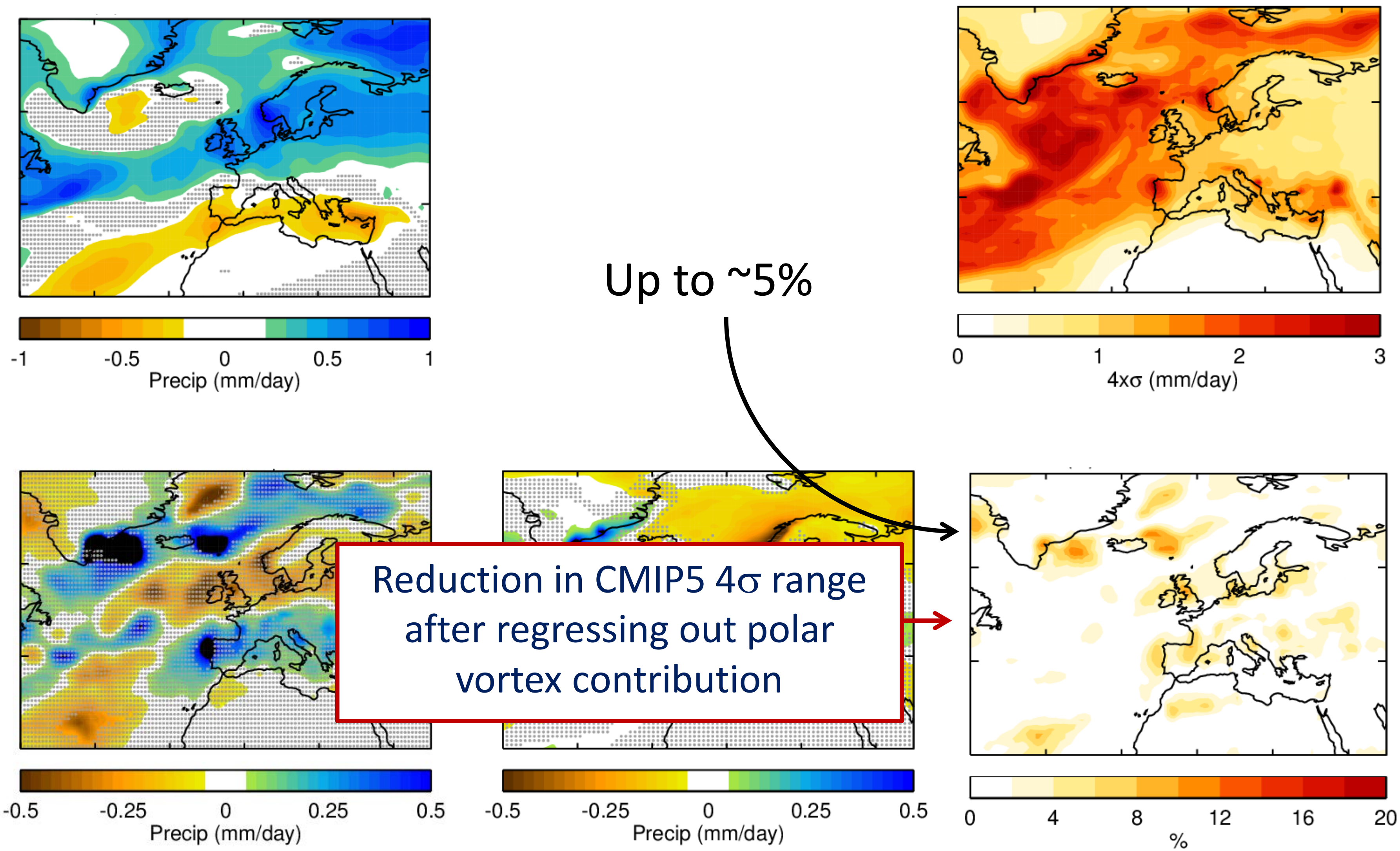


WEAK4x-STRONG4x

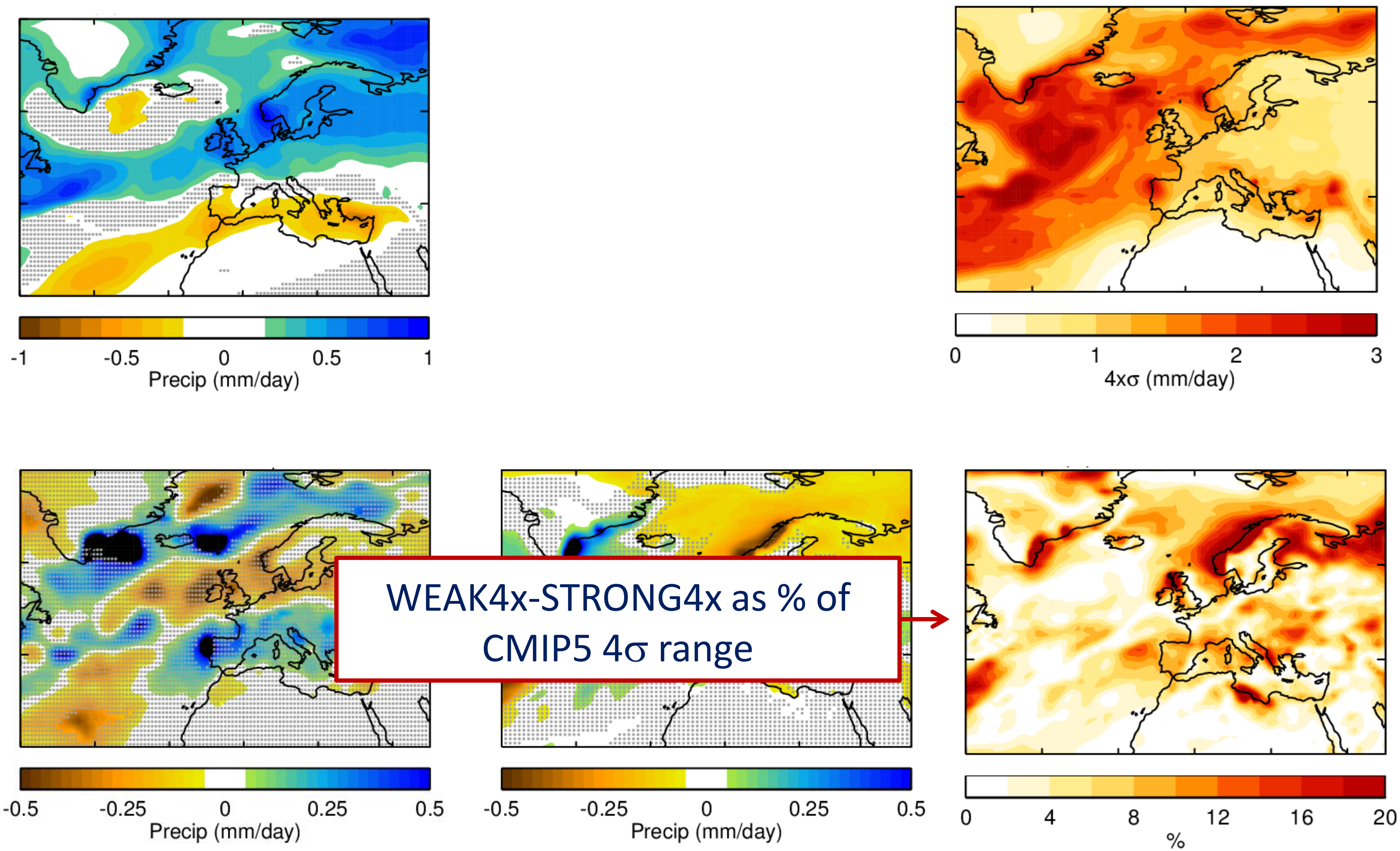

-1
-0.5
0
0.5
1
Precip (mm/day)
0
1
2
3
4xσ (mm/day)
CMIP5 4σ range
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)

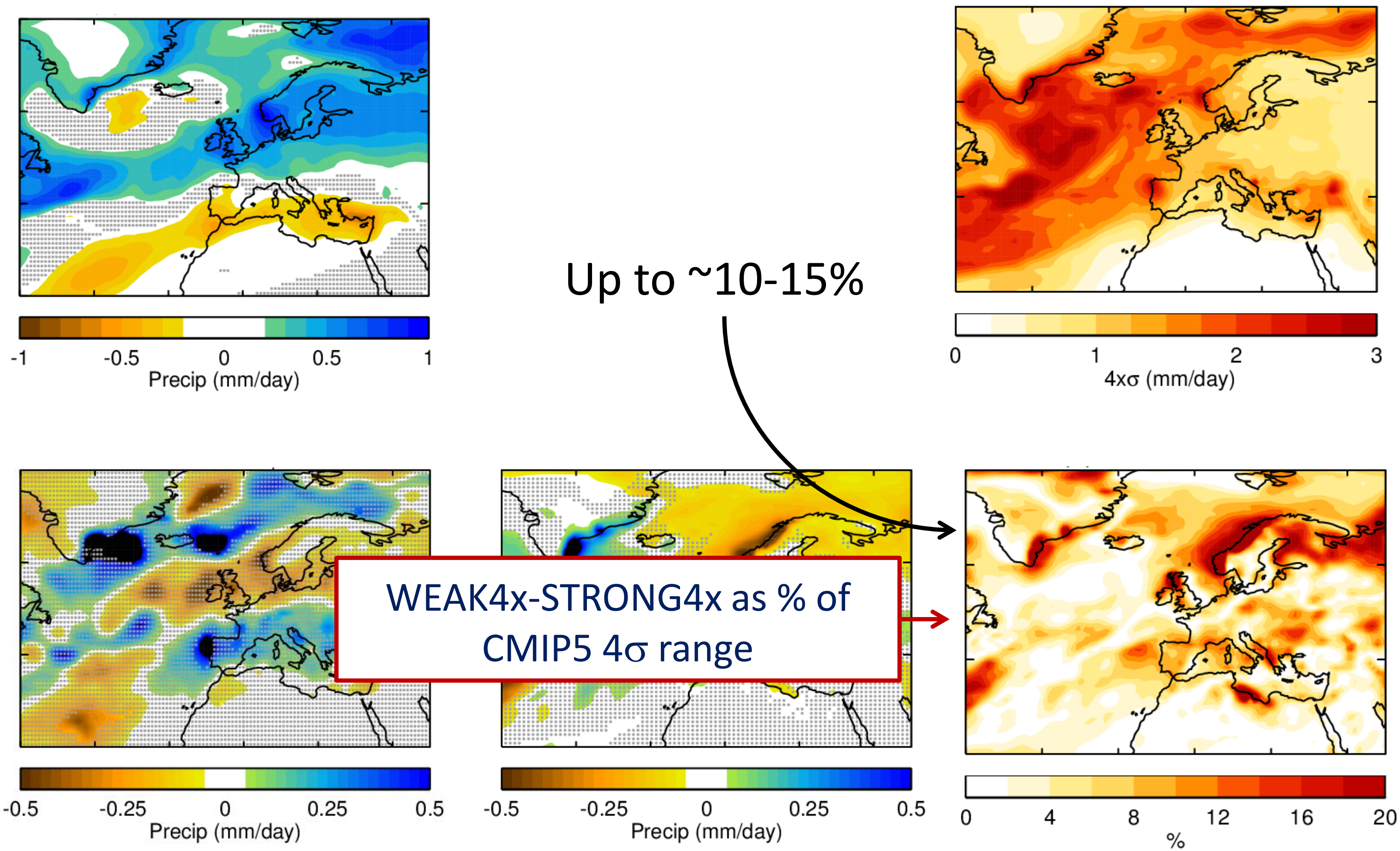


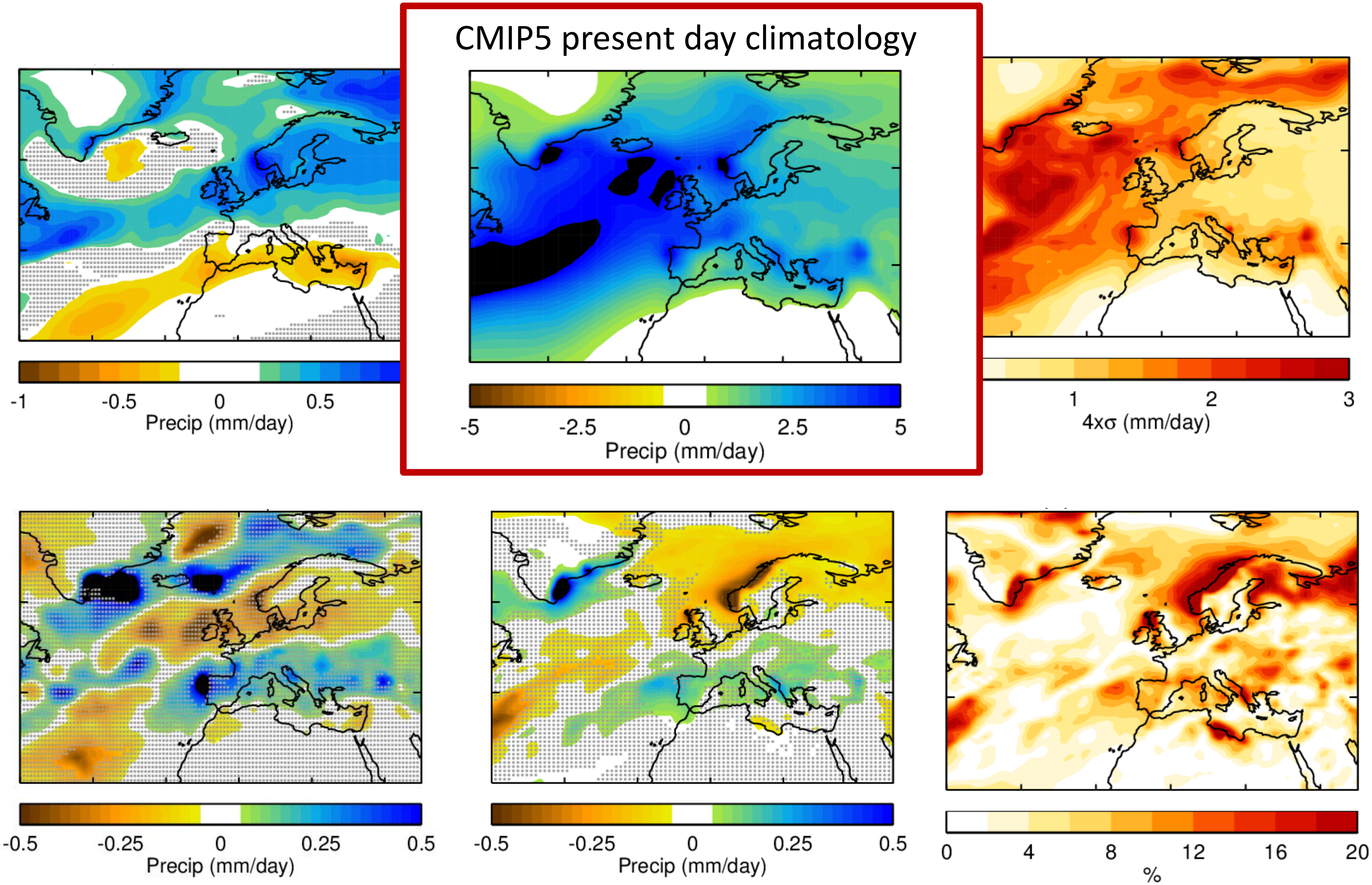
-1
-0.5
0
0.5
1
Precip (mm/day)
0
1
2
3
4xσ (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
0
4
8
12
16
20
%
Reduction in CMIP5 4σ range after regressing out polar vortex contribution



-1
-0.5
0
0.5
1
Precip (mm/day)
0
1
2
3
4xσ (mm/day)
Up to ~5%
Reduction in CMIP5 4σ range after regressing out polar vortex contribution
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
0
4
8
12
16
20
%


-1
-0.5
0
0.5
1
Precip (mm/day)
0
1
2
3
4xσ (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
WEAK4x-STRONG4x as % of CMIP5 4σ range
0
4
8
12
16
20
%


-1
-0.5
0
0.5
1
Precip (mm/day)
Up to ~10-15%
0
1
2
3
4xσ (mm/day)
WEAK4x-STRONG4x as % of CMIP5 4σ range
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
0
4
8
12
16
20
%


CMIP5 present day climatology
-1
-0.5
0
0.5
Precip (mm/day)
-5
-2.5
0
2.5
5
Precip (mm/day)
1
2
3
4xσ (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)
0
4
8
12
16
20
%

Conclusions

- Models don’t agree at all in how the NH stratospheric polar vortex will change in the future.
- Idealized experiments within one model have demonstrated that the downward influence of stratospheric change on the troposphere inferred from across-model regression, really is a downward influence.
- The contribution of stratospheric polar vortex uncertainty to the CMIP5 spread is, however, relatively small. Somewhere between 8-15% depending on what field you look at.
- But the difference between models on the extreme ends of the distribution can be large (up to 50% of the model spread for Arctic SLP and 10-15% of the model spread European precip).
- Confirms the need for an improved understanding of the reasons behind the spread on modelled polar vortex responses.

The stratospheric nudging

- Performed only on the zonal mean

Target state

Vertical Profile
1 for p<28hPa
0 for p>64hPa

$$\frac{\partial \bar{X}}{\partial t} = \cdots - K \frac{(\bar{X} - \bar{X}_0)}{\tau}$$

Timescale (6h)

The stratospheric nudging

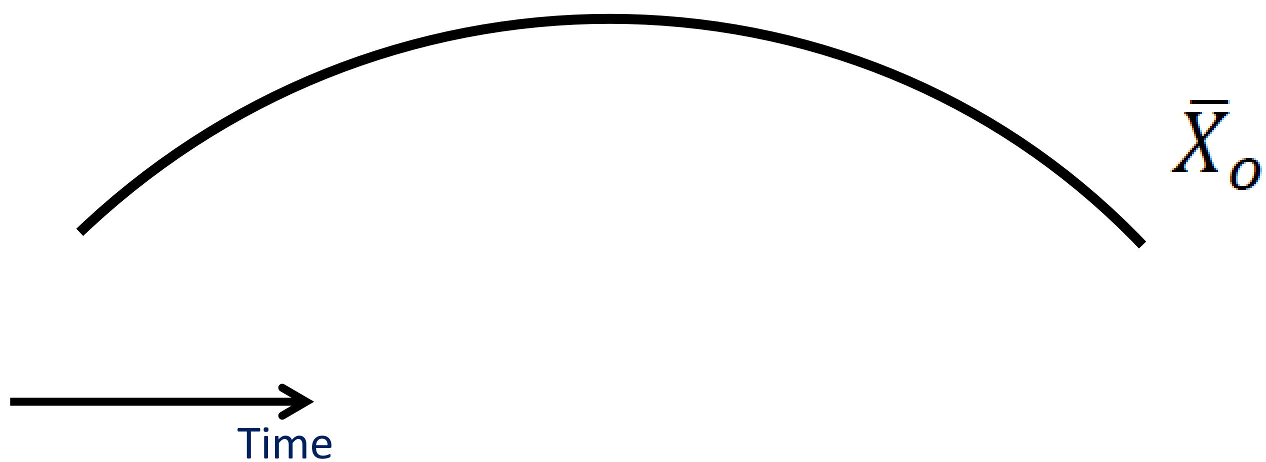
- Performed only on the zonal mean

$$\frac{\partial \bar{X}}{\partial t} = \cdots - K\frac{(\bar{X} - \bar{X}_0)}{\tau}$$

Target state

Vertical Profile
1 for p<28hPa
0 for p>64hPa

Timescale (6h)



The stratospheric nudging

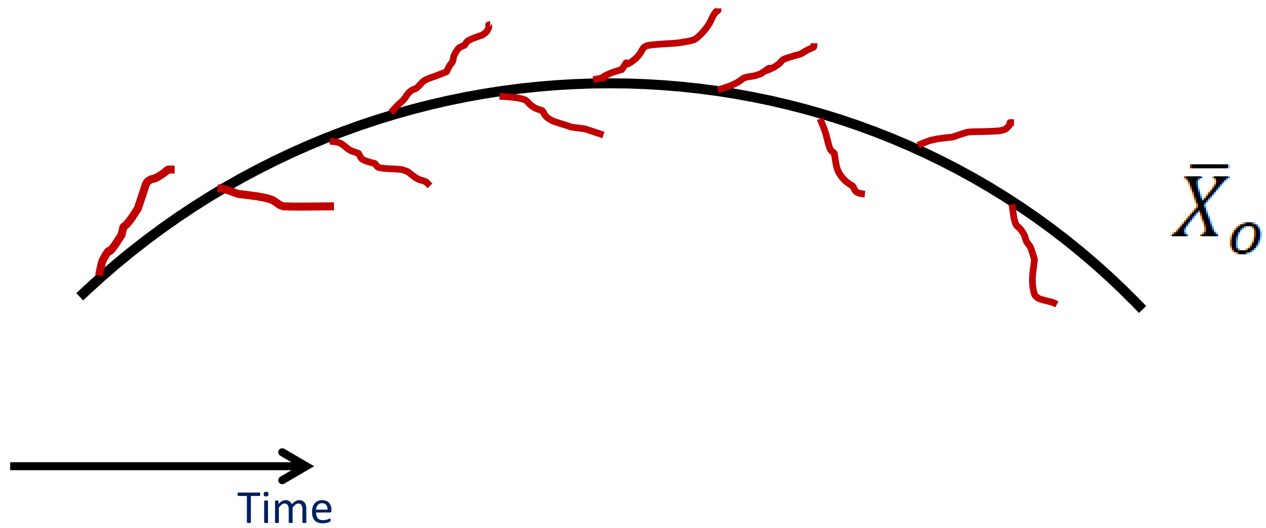
- Performed only on the zonal mean

$$\frac{\partial \bar{X}}{\partial t} = \cdots - K\,\frac{(\bar{X} - \bar{X}_0)}{\tau}$$

Target state

Vertical Profile
1 for p<28hPa
0 for p>64hPa

Timescale (6h)



The stratospheric nudging

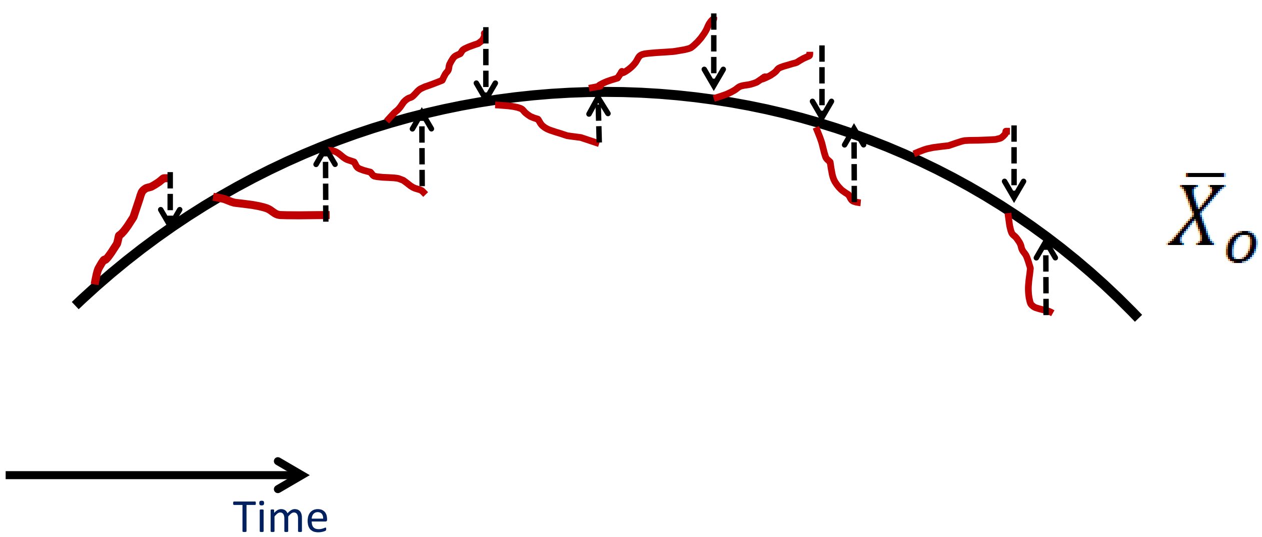
- Performed only on the zonal mean

Target state

$$\frac{\partial \bar{X}}{\partial t} = \cdots - K \frac{(\bar{X} - \bar{X}_0)}{\tau}$$

Vertical Profile
1 for p<28hPa
0 for p>64hPa

Timescale (6h)



The stratospheric nudging

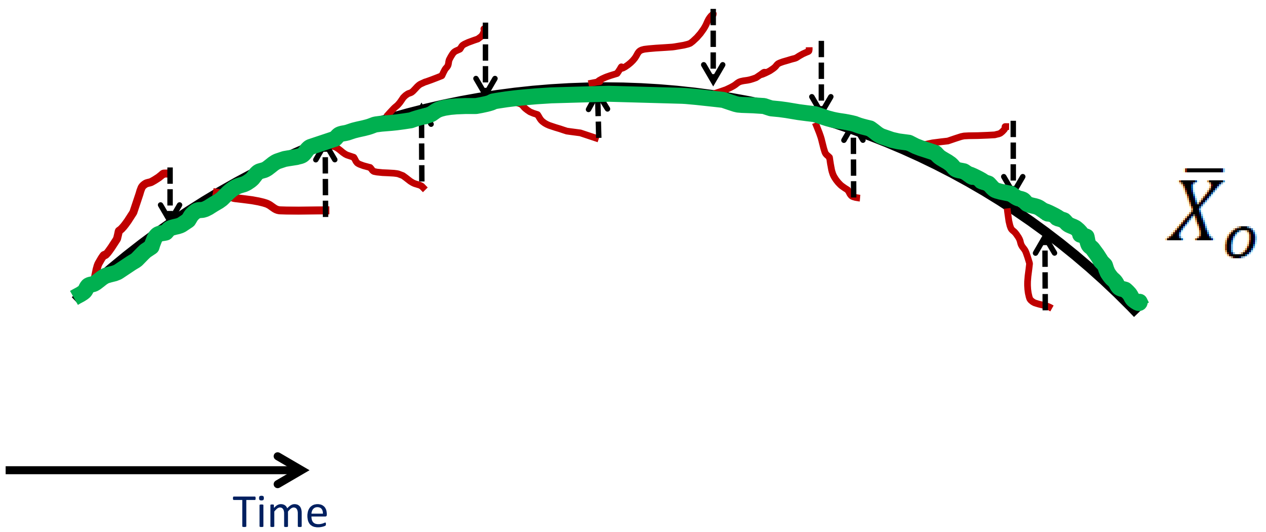
- Performed only on the zonal mean

$$\frac{\partial \bar{X}}{\partial t} = \cdots - K \frac{(\bar{X} - \bar{X}_0)}{\tau}$$

Target state

Vertical Profile
1 for p<28hPa
0 for p>64hPa

Timescale (6h)



Extra Slides

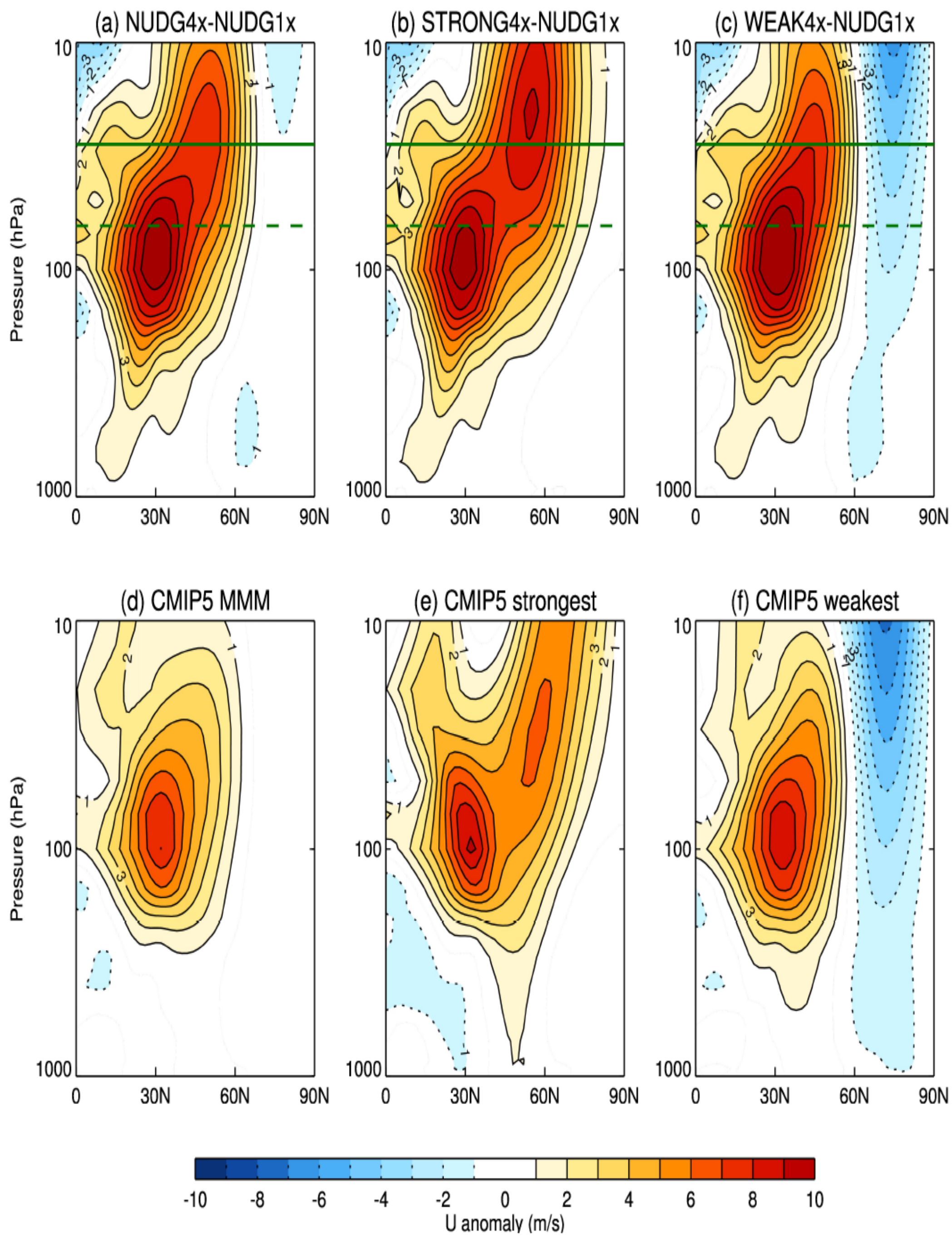
Index		A	B	C	D		A	B	C	D		CESML46	CMIP5
		4σ					σ^2					4σ	4σ
$\overline{u}$, 60^oN-65^oN		8.8	10.1	12.6	11.4		16.8	17.6	23.7	19.7		23.1	$31.9^{53.4}_{11.3}$
u, 700hPa, UK box		7.9	7.9	9.9	9.4		15.1	14.5	18.7	17.2		19.4	$30.2^{57.9}_{1.0}$
psl, Arctic		10.0	9.7	10.6	12.8		18.8	16.7	19.8	21.5		27.3	$33.1^{60.4}_{3.7}$
pr, UK box		4.4	4.1	3.2	4.3		8.6	6.5	6.2	6.8		9.3	$22.1^{47.8}_{0}$
pr, Spain box		4.0	4.1	5.1	4.8		7.8	7.9	9.9	9.3		7.9	$21.1^{46.4}_{0}$

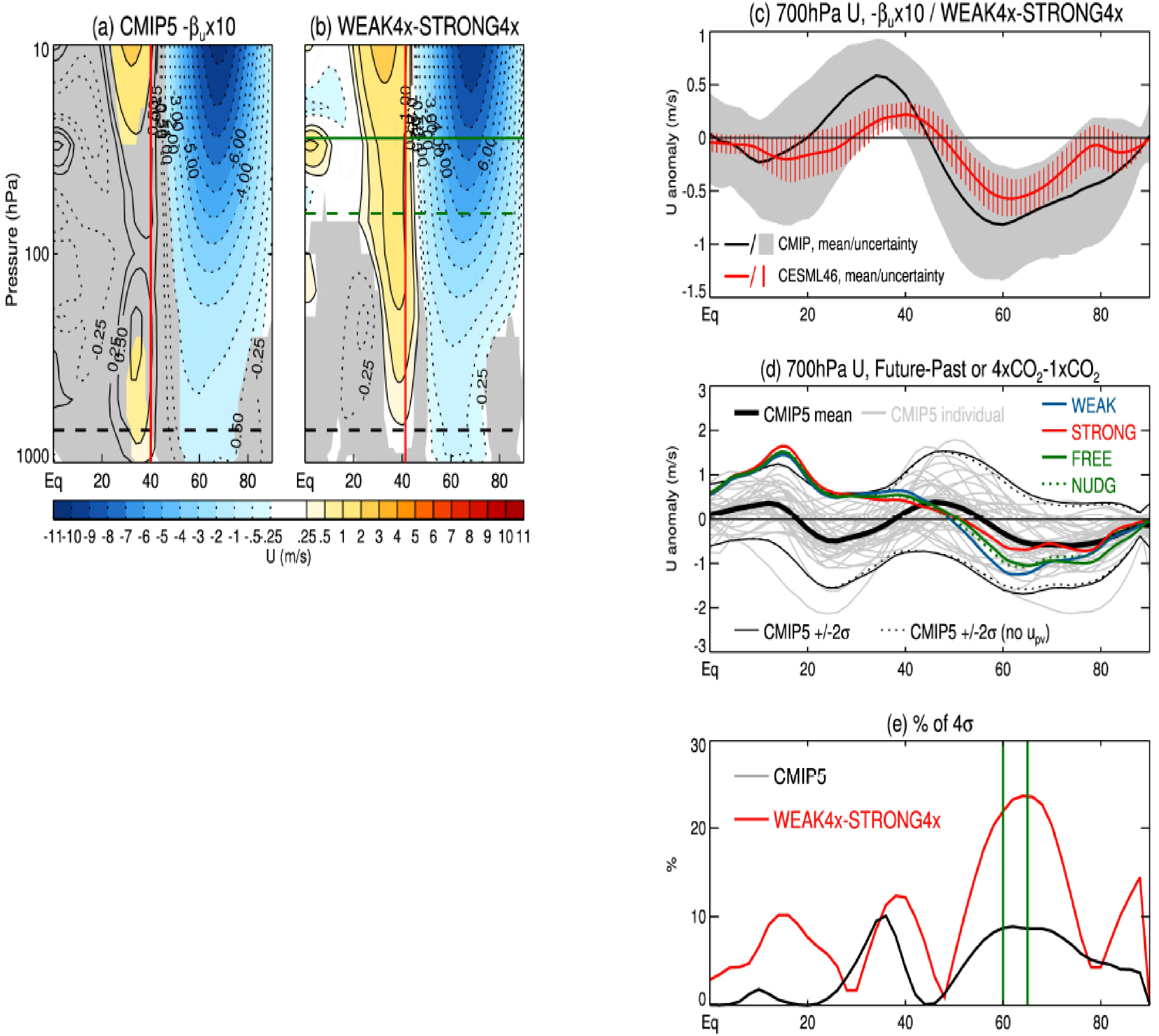
A = regressing fields onto U_pv and using 60N-75N, 10hPa

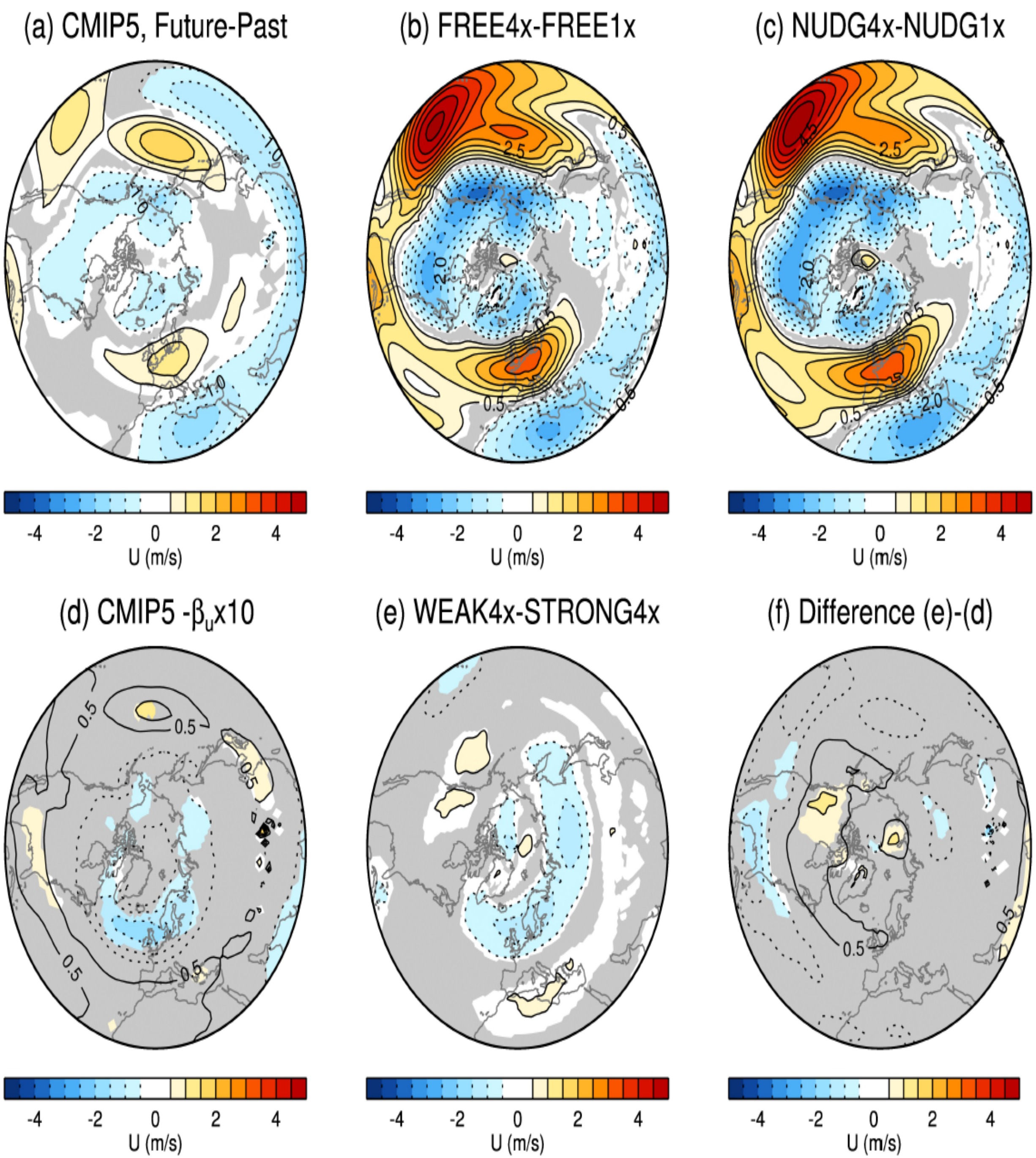
B = as A but with prior regression onto tropical upper tropospheric warming and arctic amplification.

C = as A but using 70N-80N, 10hPa

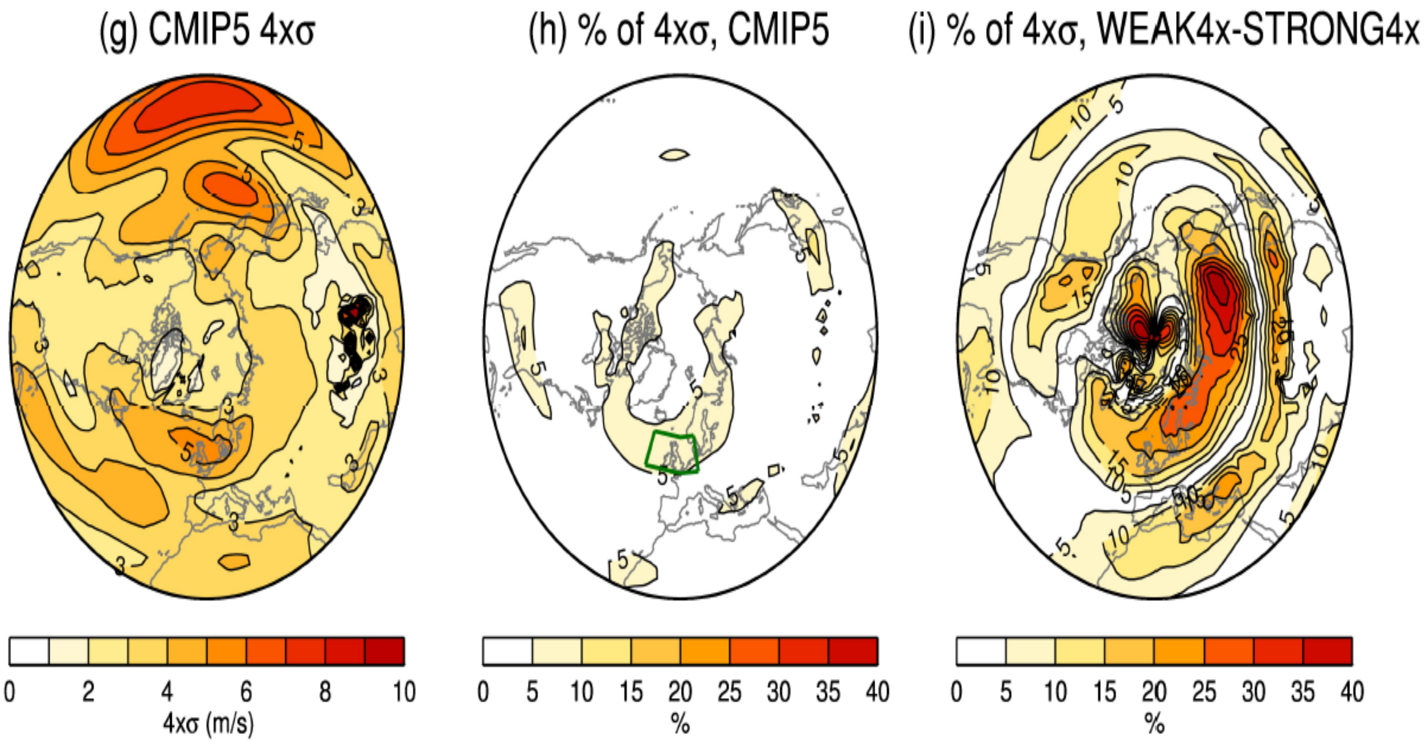
D = as B but using 70N-80N, 10hPa


(a) NUDG4x-NUDG1x
(b) STRONG4x-NUDG1x
(c) WEAK4x-NUDG1x
(d) CMIP5 MMM
(e) CMIP5 strongest
(f) CMIP5 weakest
Pressure (hPa)
10
100
1000
0
30N
60N
90N
-10
-8
-6
-4
-2
0
2
4
6
8
10
U anomaly (m/s)

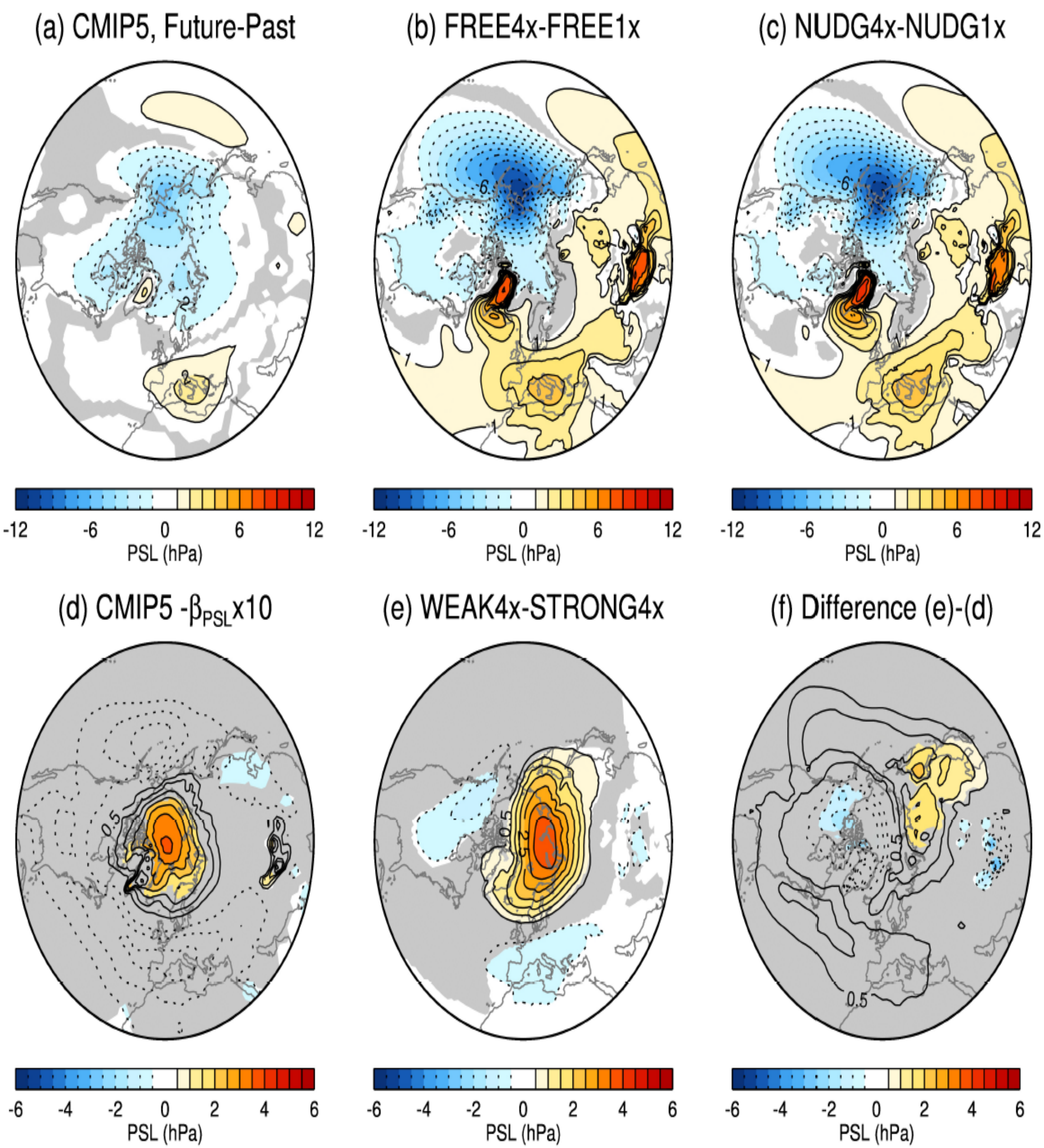

(a) CMIP5 -β_ux10
(b) WEAK4x-STRONG4x
Pressure (hPa)
10
100
1000
Eq 20 40 60 80
-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 -.5 -.25 .25 .5 1 2 3 4 5 6 7 8 9 10 11
U (m/s)
(c) 700hPa U, -β_ux10 / WEAK4x-STRONG4x
U anomaly (m/s)
CMIP, mean/uncertainty
CESML46, mean/uncertainty
(d) 700hPa U, Future-Past or 4xCO_2-1xCO_2
CMIP5 mean
CMIP5 individual
WEAK
STRONG
FREE
NUDG
CMIP5 +/-2σ
CMIP5 +/-2σ (no u_{pv})
(e) % of 4σ
%
CMIP5
WEAK4x-STRONG4x



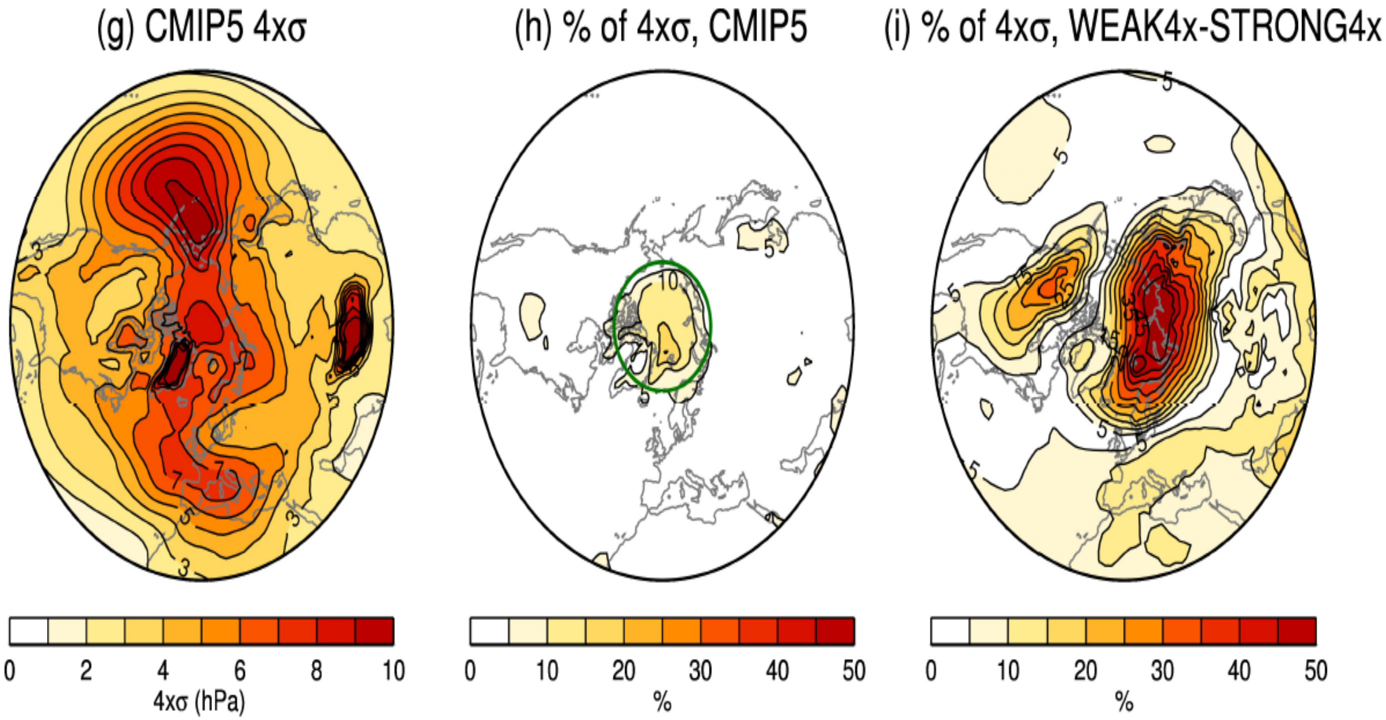
(a) CMIP5, Future-Past
(b) FREE4x-FREE1x
(c) NUDG4x-NUDG1x
(d) CMIP5 -βux10
(e) WEAK4x-STRONG4x
(f) Difference (e)-(d)
-4 -2 0 2 4
U (m/s)



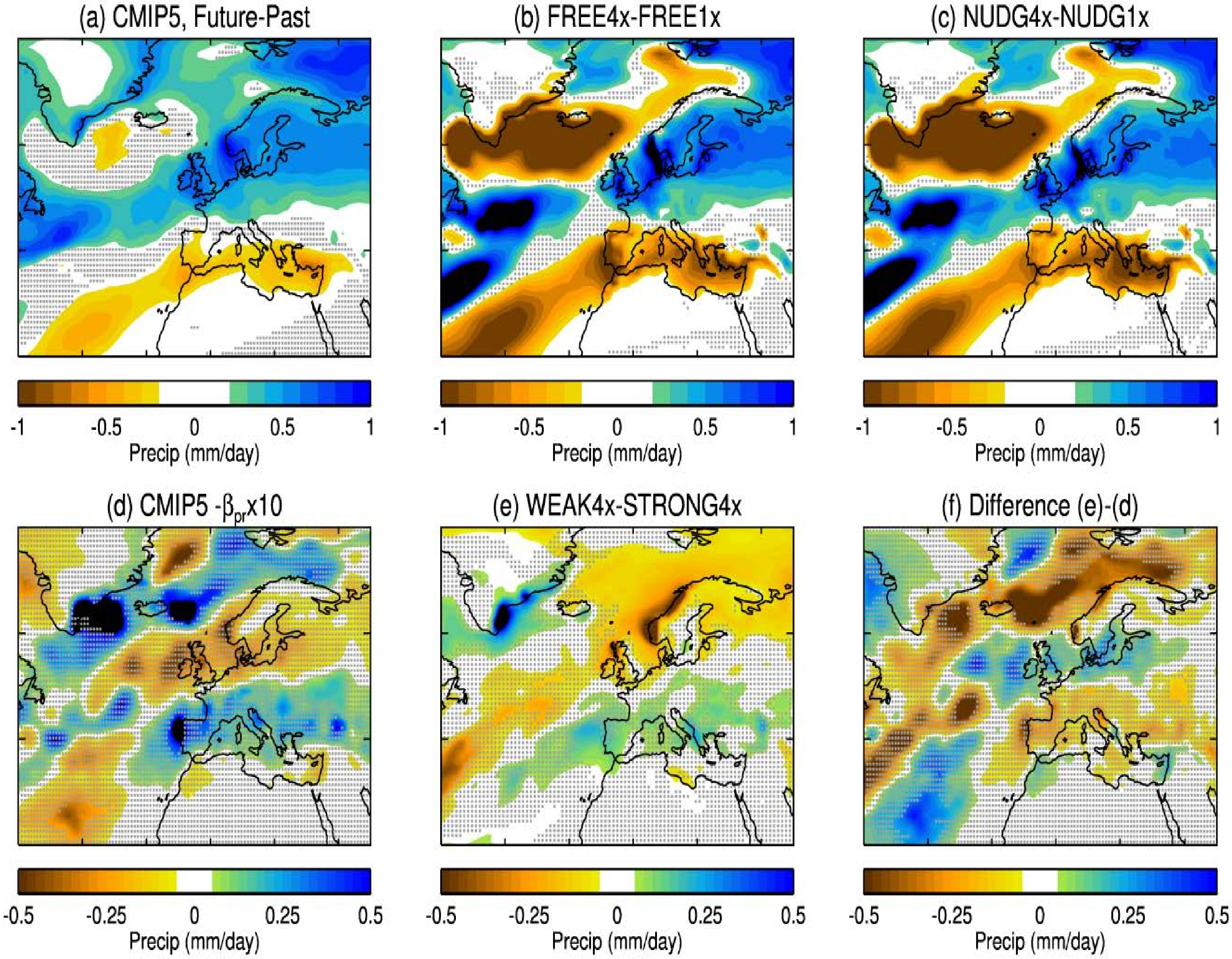
(g) CMIP5 4xσ
(h) % of 4xσ, CMIP5
(i) % of 4xσ, WEAK4x-STRONG4x
0 2 4 6 8 10
4xσ (m/s)
0 5 10 15 20 25 30 35 40
%
0 5 10 15 20 25 30 35 40
%



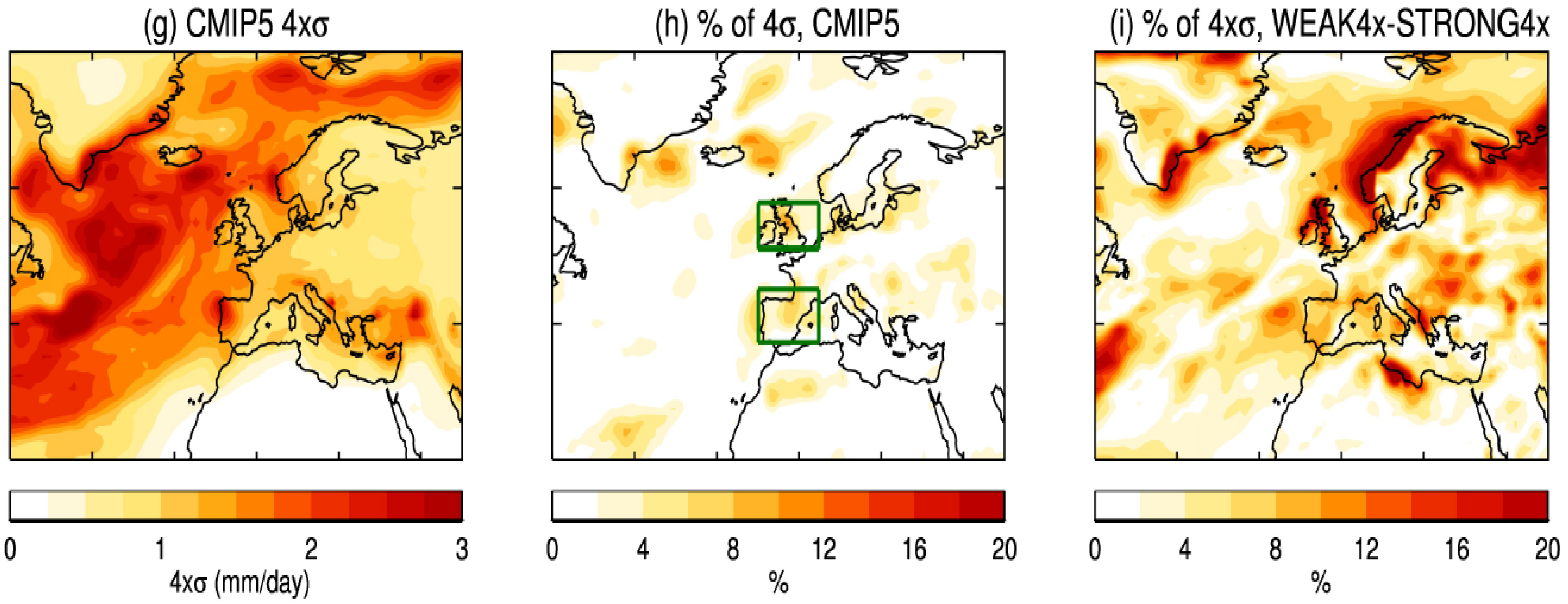
(a) CMIP5, Future-Past
(b) FREE4x-FREE1x
(c) NUDG4x-NUDG1x
-12 -6 0 6 12
PSL (hPa)
(d) CMIP5 -β_{PSL}x10
(e) WEAK4x-STRONG4x
(f) Difference (e)-(d)
-6 -4 -2 0 2 4 6
PSL (hPa)



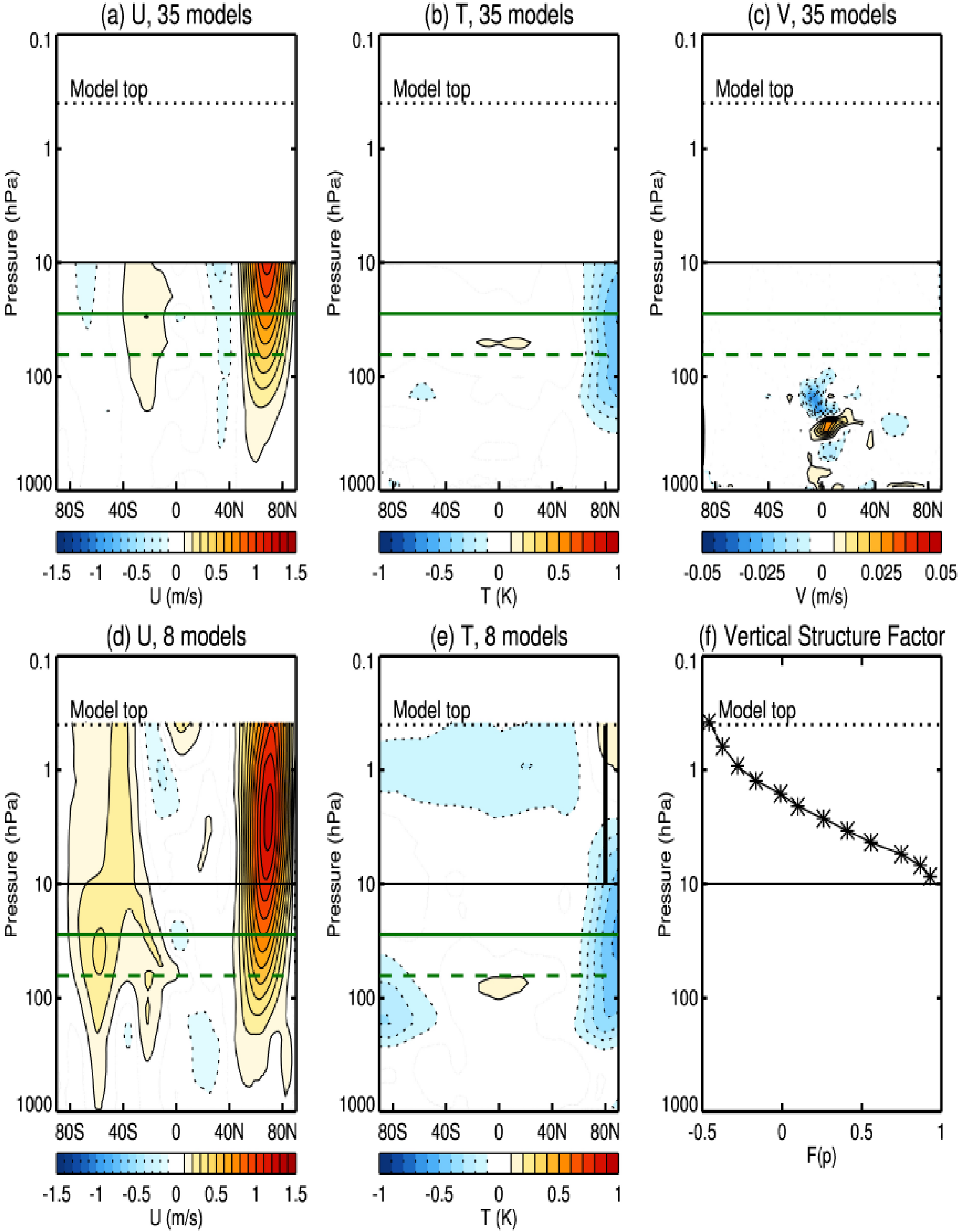
(g) CMIP5 4xσ
(h) % of 4xσ, CMIP5
(i) % of 4xσ, WEAK4x-STRONG4x
0
2
4
6
8
10
4xσ (hPa)
0
10
20
30
40
50
%
0
10
20
30
40
50
%



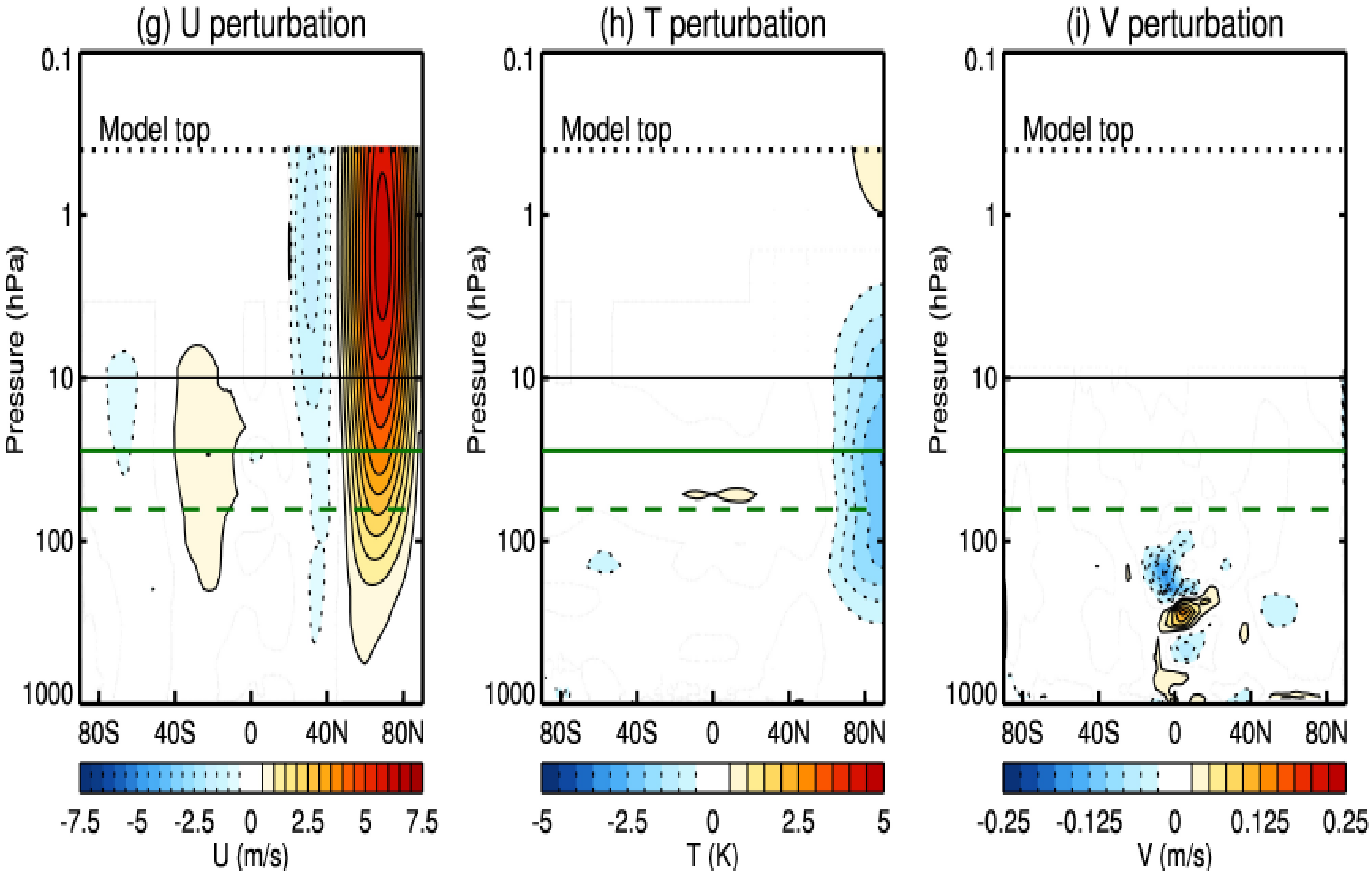
(a) CMIP5, Future-Past
(b) FREE4x-FREE1x
(c) NUDG4x-NUDG1x
-1
-0.5
0
0.5
1
Precip (mm/day)
(d) CMIP5 -β_{pr}x10
(e) WEAK4x-STRONG4x
(f) Difference (e)-(d)
-0.5
-0.25
0
0.25
0.5
Precip (mm/day)

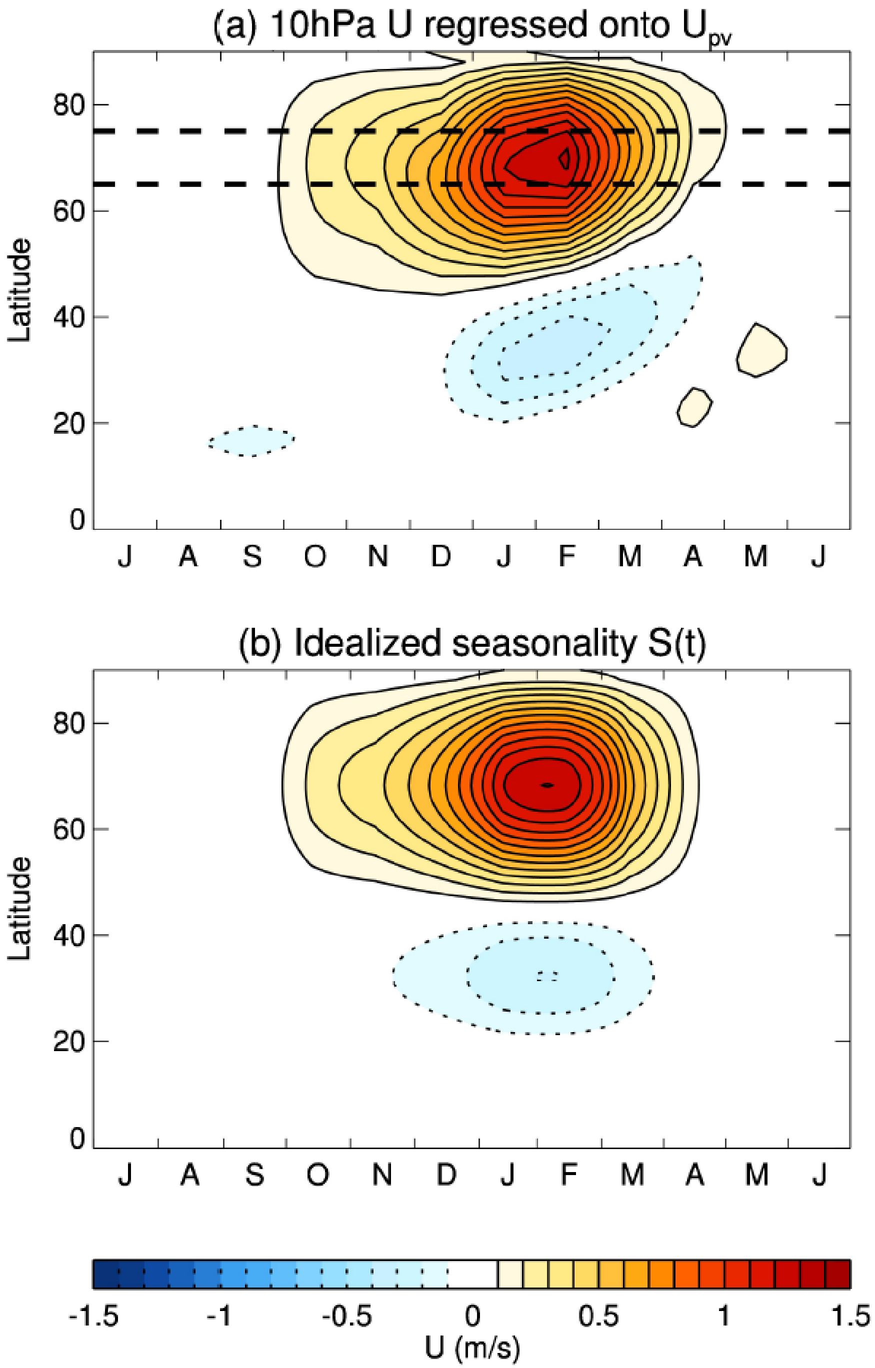


(g) CMIP5 4xσ
0
1
2
3
4xσ (mm/day)
(h) % of 4σ, CMIP5
0
4
8
12
16
20
%
(i) % of 4xσ, WEAK4x-STRONG4x
0
4
8
12
16
20
%



(a) U, 35 models
(b) T, 35 models
(c) V, 35 models
Model top
Pressure (hPa)
0.1
1
10
100
1000
80S
40S
0
40N
80N
-1.5
-1
-0.5
0
0.5
1
1.5
U (m/s)
T (K)
-0.05
-0.025
0.025
0.05
V (m/s)
(d) U, 8 models
(e) T, 8 models
(f) Vertical Structure Factor
F(p)


(g) U perturbation
(h) T perturbation
(i) V perturbation
Model top
Pressure (hPa)
0.1
1
10
100
1000
80S
40S
0
40N
80N
-7.5
-5
-2.5
0
2.5
5
7.5
U (m/s)
-5
-2.5
0
2.5
5
T (K)
-0.25
-0.125
0
0.125
0.25
V (m/s)



(a) 10hPa U regressed onto U_{pv}
Latitude
0
20
40
60
80
J A S O N D J F M A M J
(b) Idealized seasonality S(t)
Latitude
0
20
40
60
80
J A S O N D J F M A M J
-1.5 -1 -0.5 0 0.5 1 1.5
U (m/s)