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Dependence of atmospheric teleconnections on biases in stratospheric circulation

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Research Question

- ✓ Models are only approximate representations of the real world
- ✓ Models cannot resolve sub-grid processes, whose effects are included only approximately, through parameterisations
- ✓ As a result, statistical properties of model-simulated Earth's climate (e.g. mean climate aka climatology) differ from the (best estimate of) real Earth's climate. **Models have biases.**

Question:

How do model's biases affect atmospheric teleconnections which provide source for sub-seasonal to seasonal climate predictability?



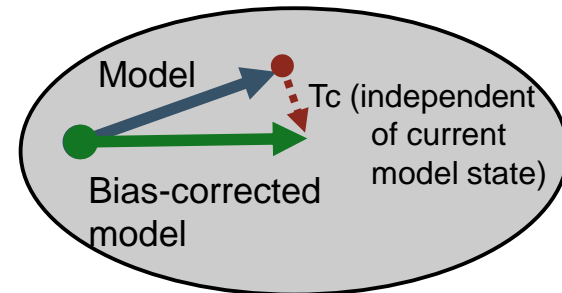
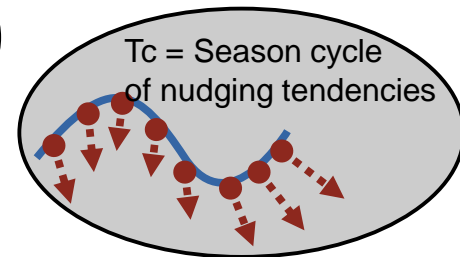
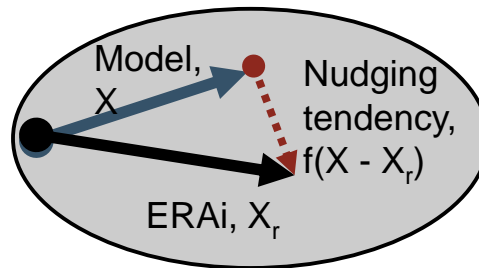
Bias correction technique



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Bias Corrections

- ECHAM6 AGMC T63L95
- Two-step correction process
winds, surface pressure
- 1) • Nudge towards ERA Interim.
 - Record 6-hrly nudging tendencies to create a 12 month climatology of inherent bias.
- 2) • Re-run model, remove bias at each time-step.



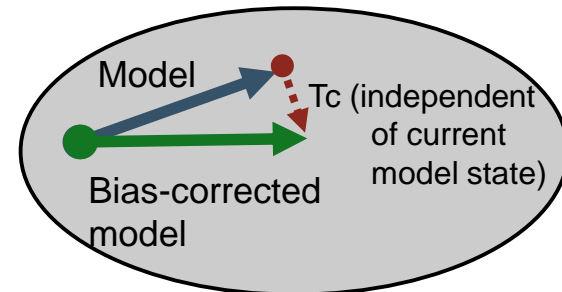
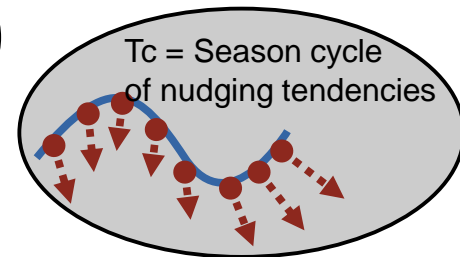
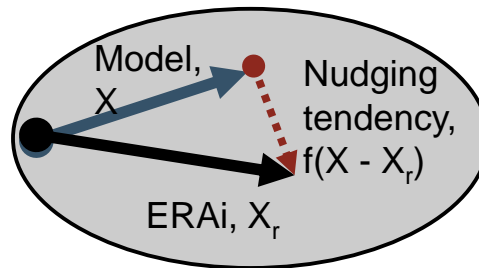
Kharin & Scinocca, 2012

Simpson, et al., 2013

Chang, et al., 2019, Schubert, et al., 2019

Bias Corrections

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- 1) • Nudge towards ERA Interim.
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- *Key Points*
- Bias-corrections are independent of current model state.
- Bias-corrected model can respond to perturbations.

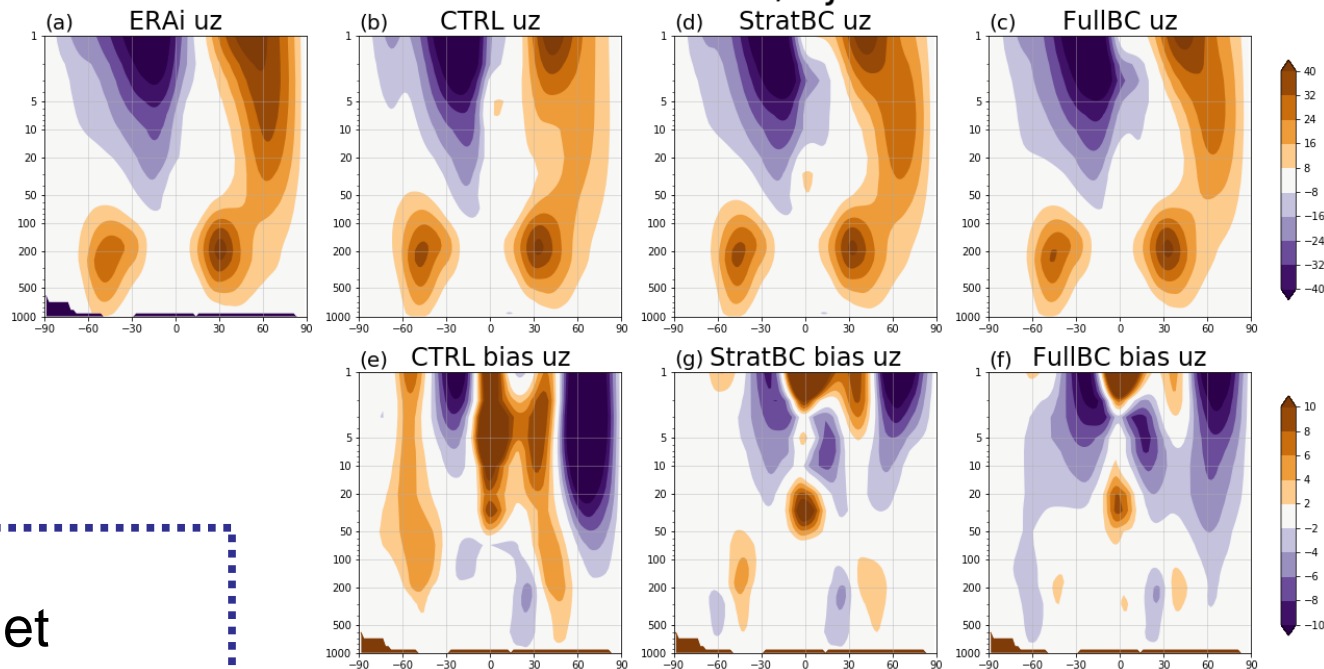


Bias Corrections – Zonal Wind

Zonal mean zonal u, djf

- 3 experiments:
- Control
- Strat. Bias-Corr
 - ~100hPa~1hPa
- Full Bias-Corr
 - ~850hPa~1hPa

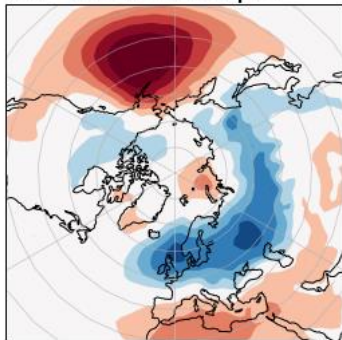
Key point: bias in stratospheric polar jet reduced by ~ 70%



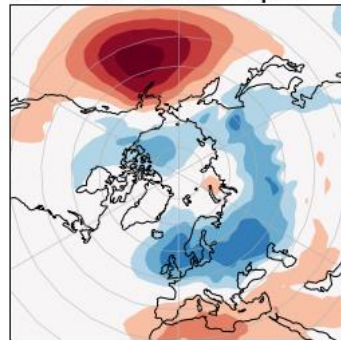
Bias Corrections – Surface Pressure

- 3 experiments:
- Control
- Strat. Bias-Corr
 - ~100hPa~1hPa
- Full Bias-Corr
 - ~850hPa~1hPa

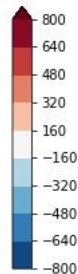
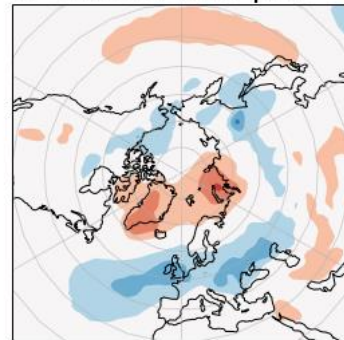
(h) CTRL bias psl



(j) StratBC bias psl



(i) FullBC bias psl



Key point: CTRL and StratBC have similar surface pressure bias.



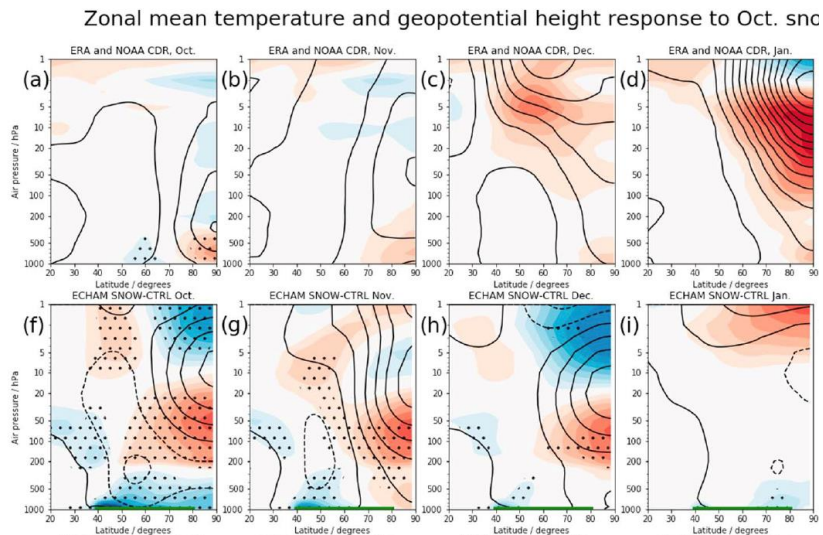
Response to October snow cover



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October snow cover experiment

- ✓ Eurasian October snow cover is a controversial driver of wintertime mean NAM
- ✓ A negative wintermean NAM signal is apparently seen in observations following Octobers with large snow extent (Cohen and Entekhabi, 1999; Cohen et al. 2010) due to "upward propagating Rossby wave – weakened stratospheric vortex – downward NAM propagation" mechanism (Cohen et al. 2007)
- ✓ ... but the effect is not reproduced by free-running models (Hardiman et al. 2008, Furtado et al. 2015, Tyrrell et al. 2018), possibly due to model biases (Smith et al. 2011)



Tyrrell et al., 2018

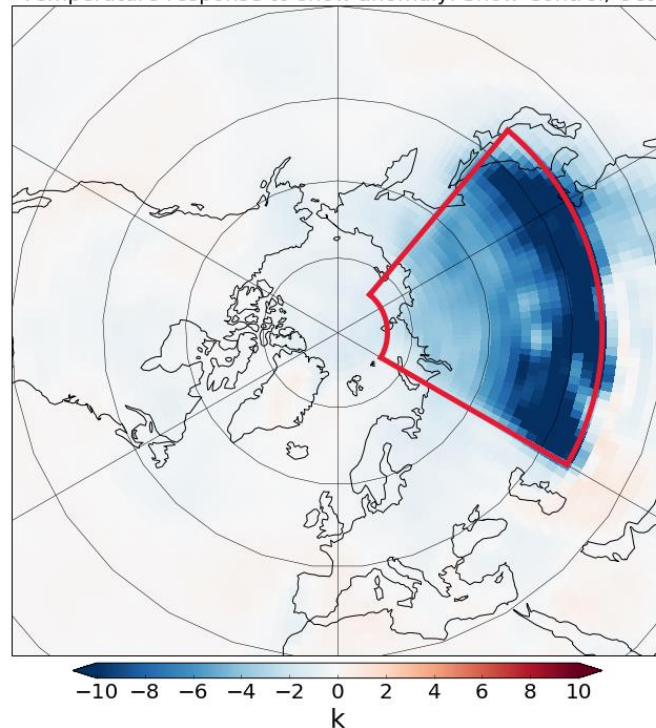
Question:

Will a model with alleviated biases capture the snow-NAM teleconnection?

October Snow Cover Experiment

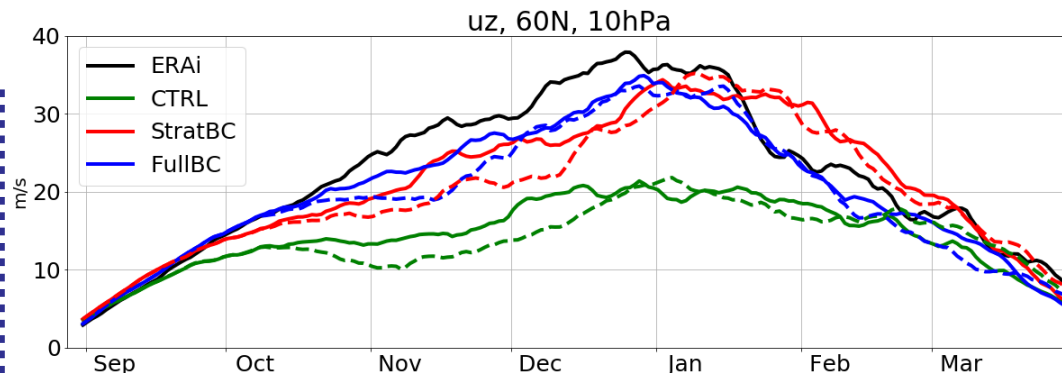
- Snow cover added over Siberia in October.
 - SWE=100 kg m⁻²
- 100 winters snow/control.
- For CTRL, StratBC, FullBC.

Temperature response to snow anomaly. Snow-Control, Oct



Polar vortex response to snow

- *Key points:*
- Clear increase in vortex strength in bias corrected runs

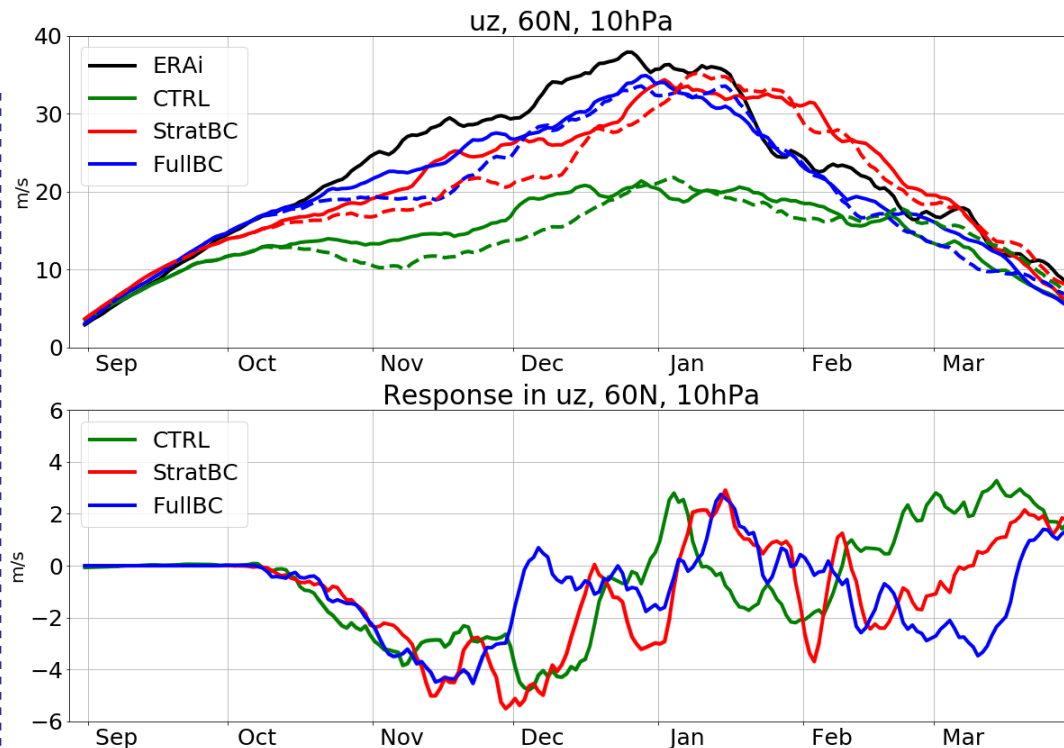


Daily zonal mean wind 60N, 10hPa.
Dashed lines = Snow experiment



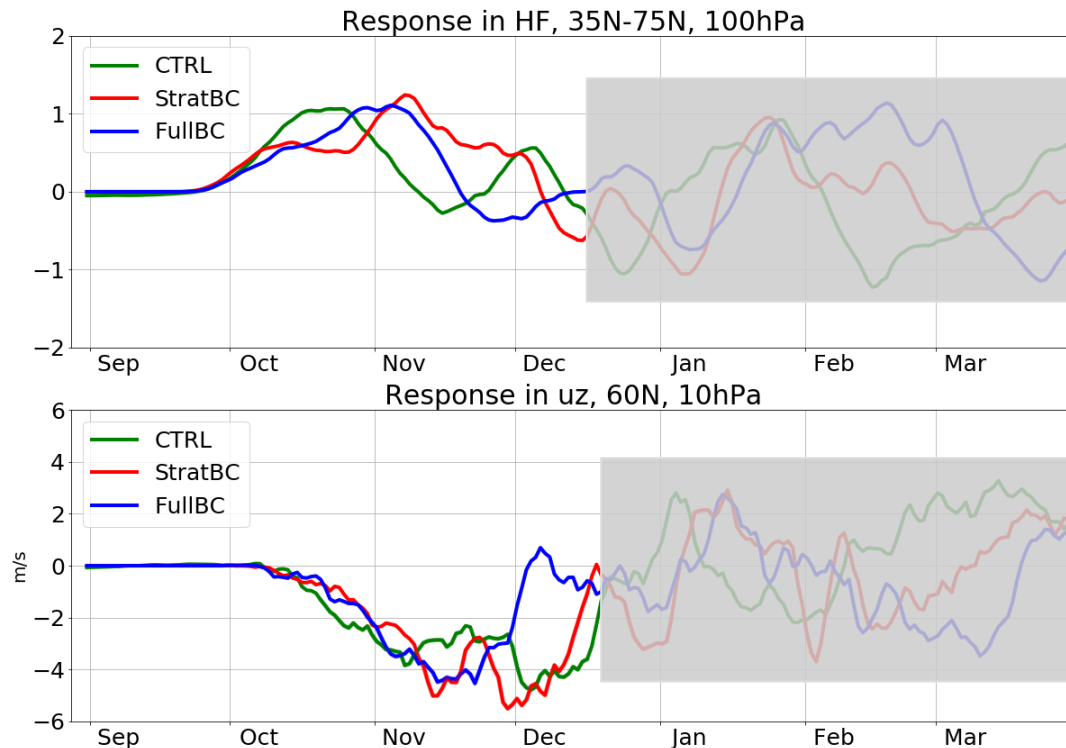
Polar vortex response to snow

- *Key points:*
- Clear increase in vortex strength in bias corrected runs
- yet no significant difference in magnitude of vortex response to snow.
- Difference in timing of vortex recovery.



Heat Flux response to snow

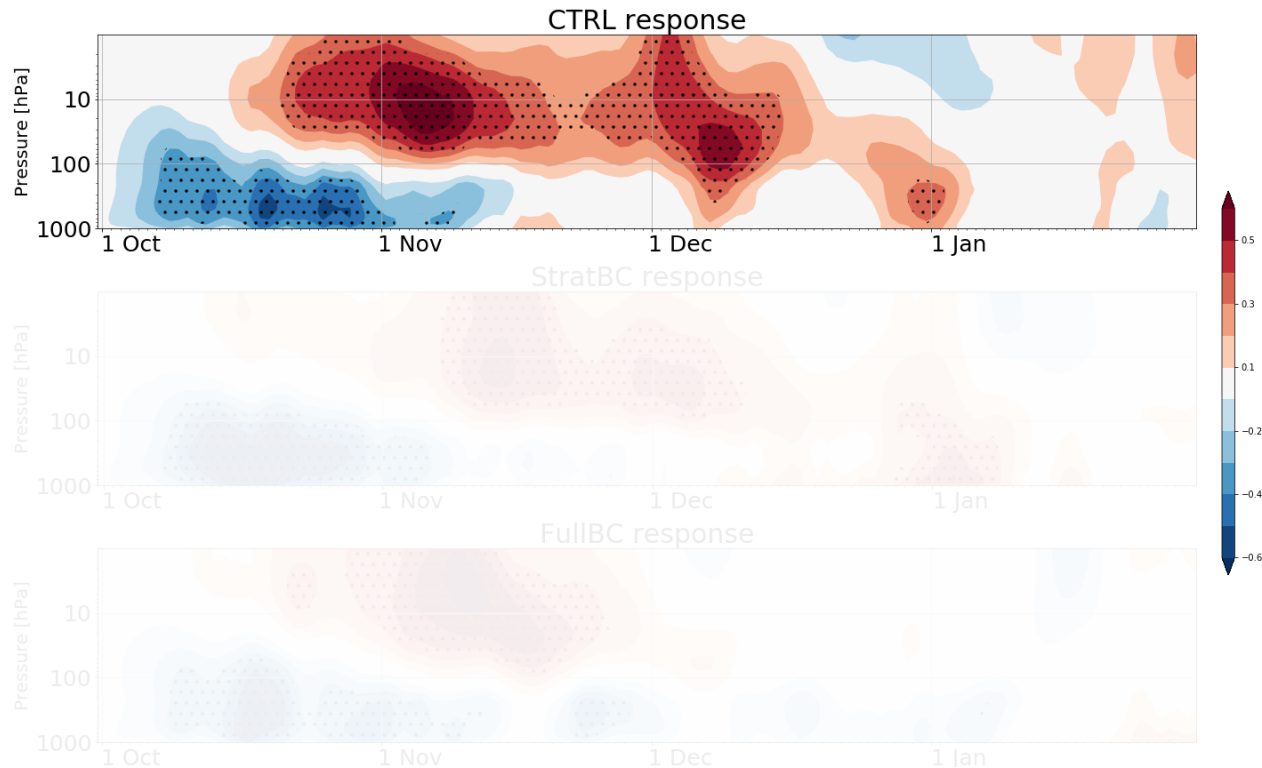
- *Key points:*
- Heat flux response has similar max magnitude between climatologies
- CTRL has two peaks, FullBC one peak, StratBC positive HF for Oct, Nov.



Polar cap geopotential height response to snow

➤ CTRL

- ✓ Weak surface response in Dec



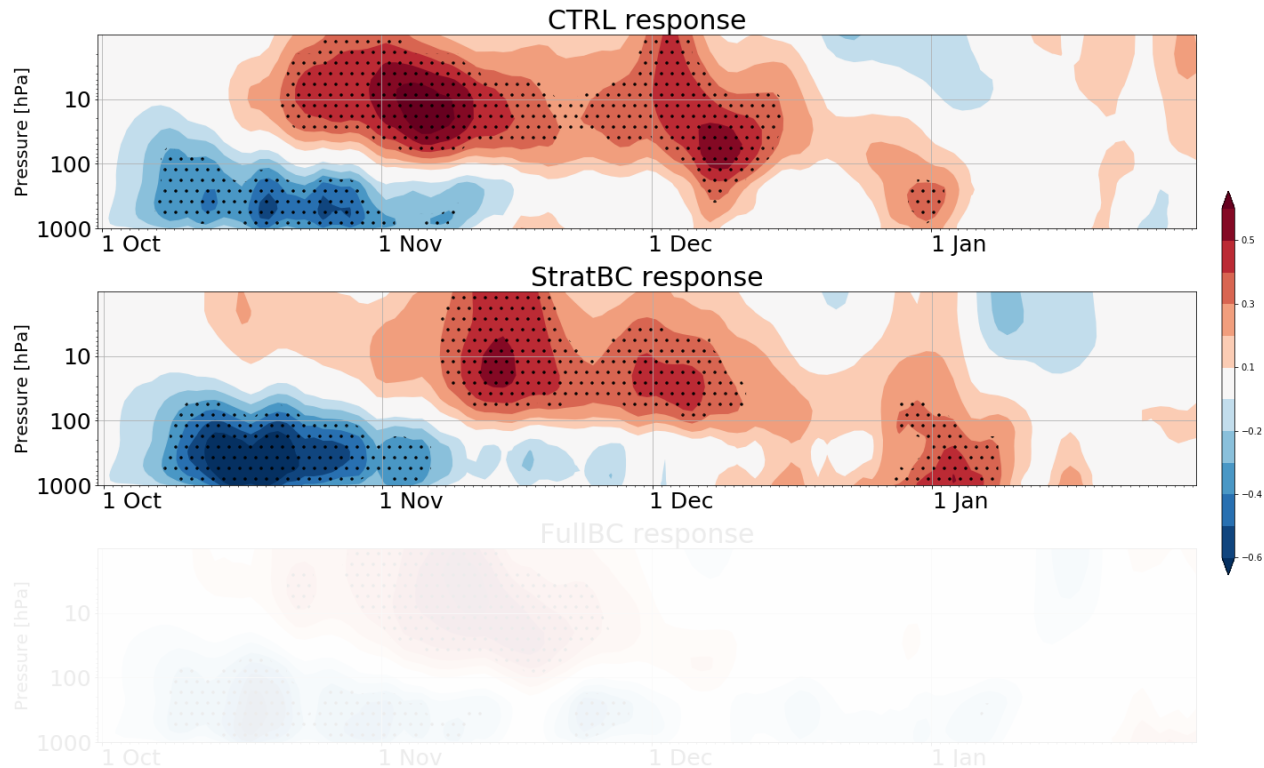
Polar cap geopotential height response to snow

➤ CTRL

- ✓ Weak surface response in Dec

➤ StratBC

- ✓ Surface response in Dec



Polar cap geopotential height response to snow

➤ CTRL

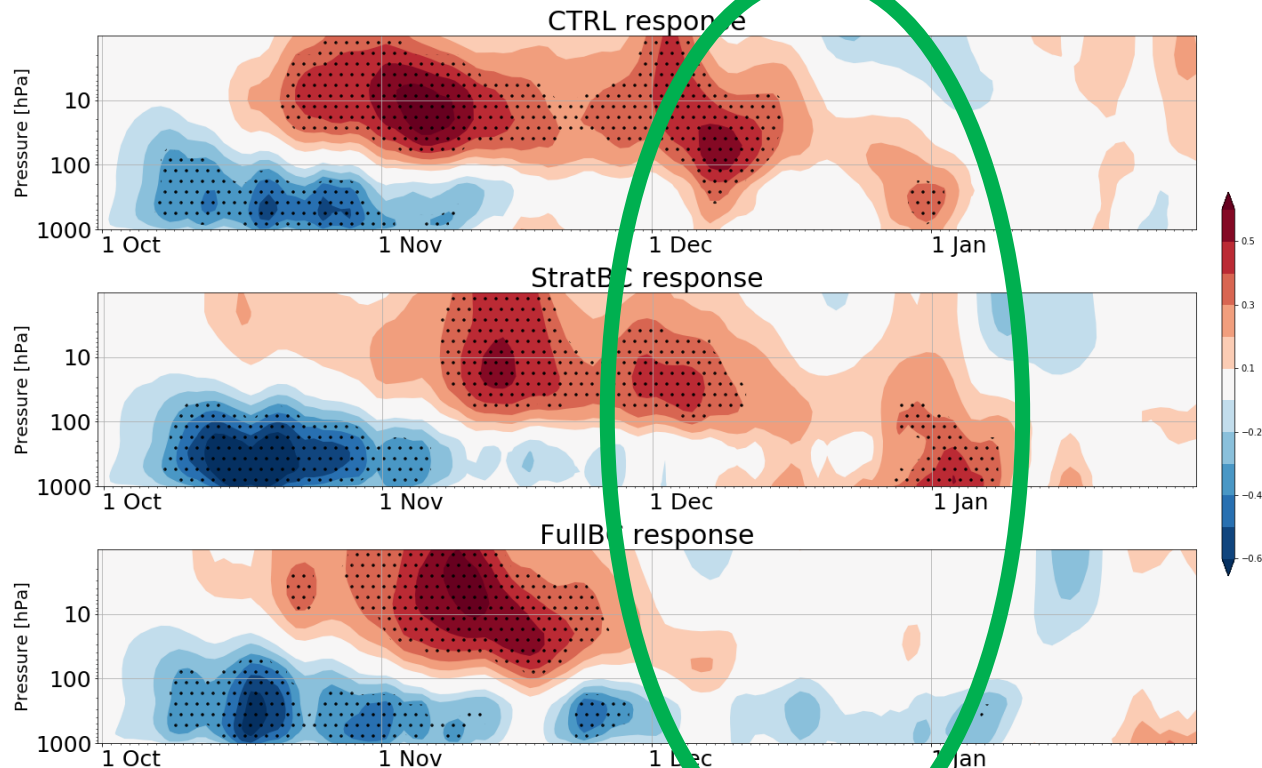
- ✓ Weak surface response in Dec

➤ StratBC

- ✓ Surface response in Dec

➤ FullBC

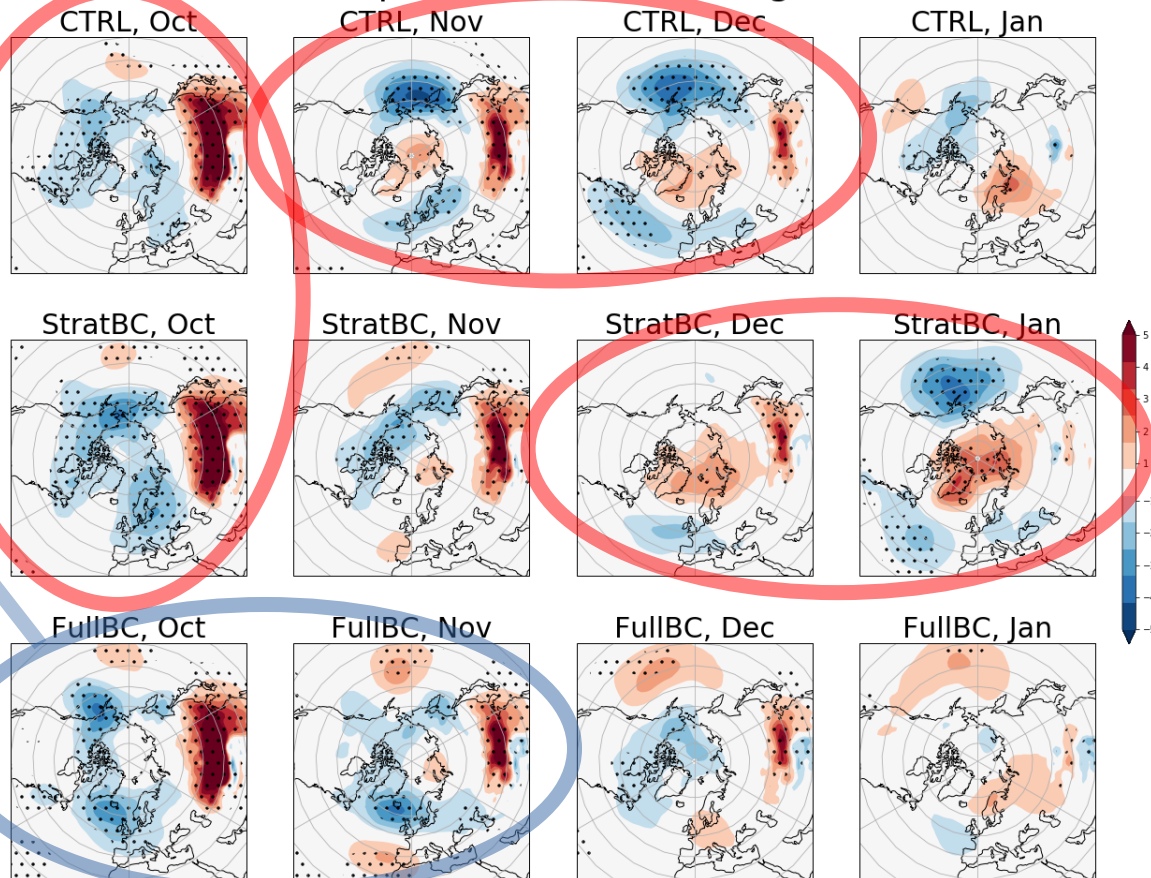
- ✓ No (negative NAM) surface response



Surface pressure response to snow

- Similarity of initial tropospheric response to snow between CTRL and StratBC

SLP response to snow forcing



What causes different response?

- Different phase of the stationary waves (Smith et al. 2010)?

NO!

- Climatological position of the eddy-driven jet (Garfinkel et al. 2013)?

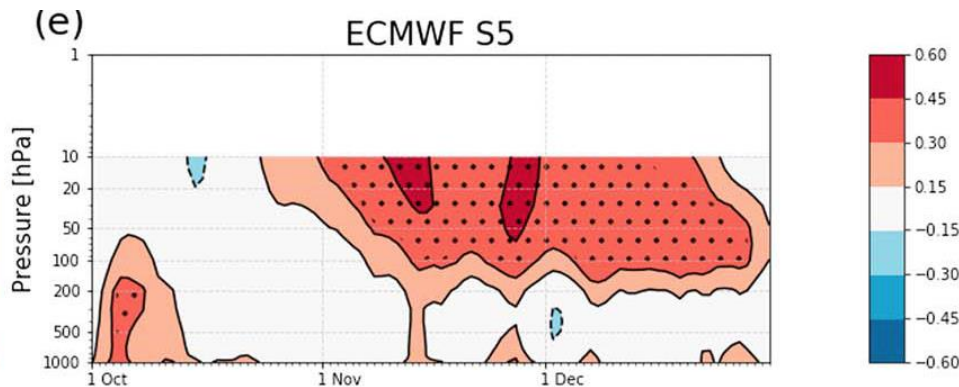
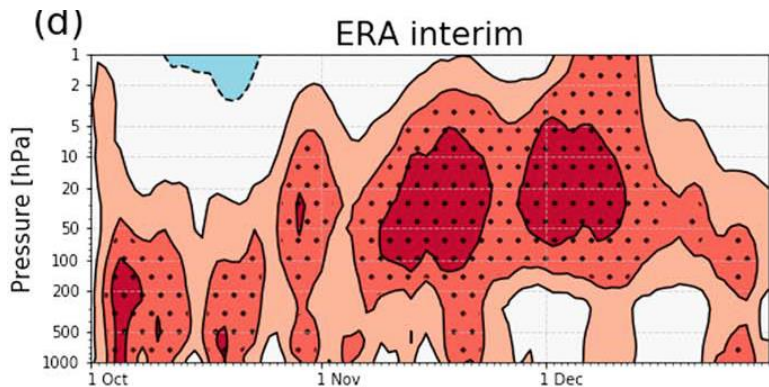
NO!

- Differences in initial tropospheric response leading to different preconditioning?

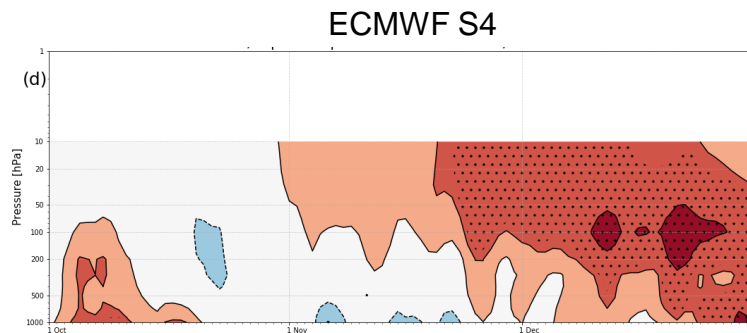
MAYBE..



Siberian surface forcing in ECMWF model



- Siberian surface temperatures in October weaken stratospheric vortex in Nov-Dec
- Reproduced by ECMWF model with some differences between S4 and S5
- Due to different biases?

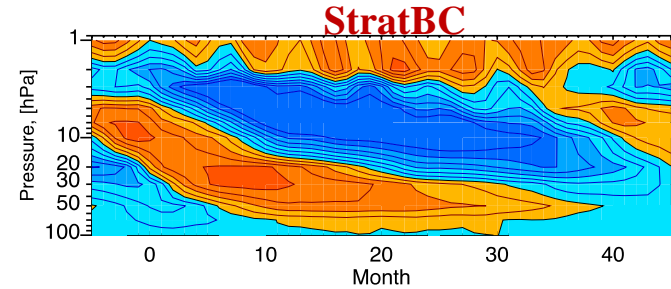
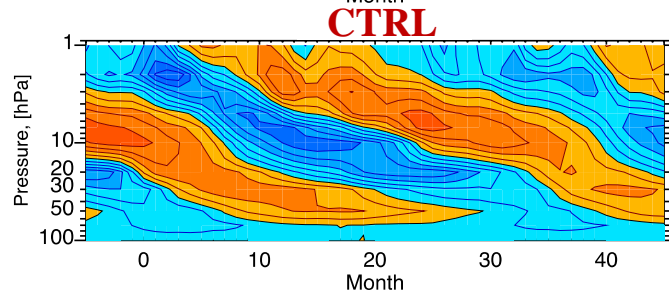
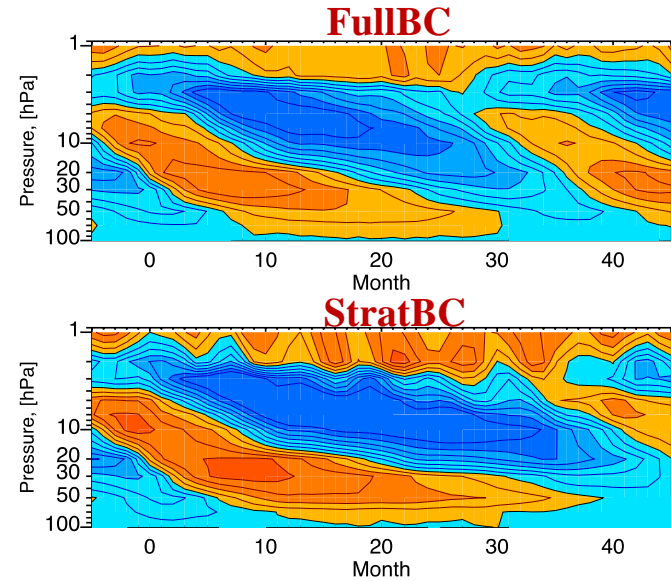
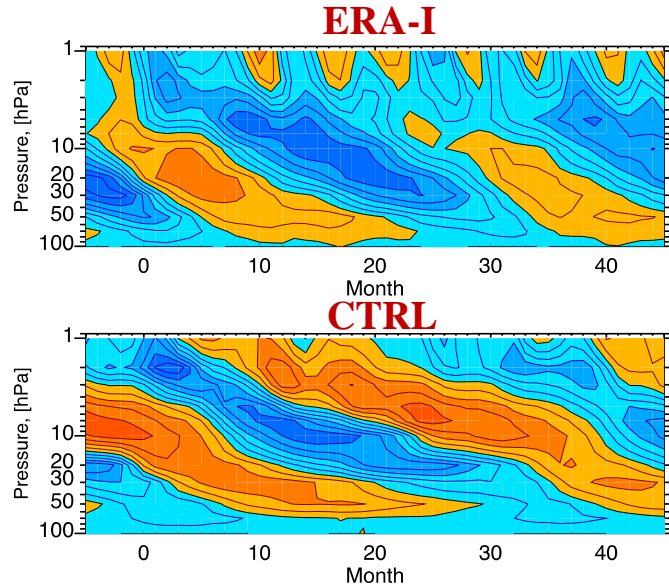


Extratropical response to QBO



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QBO in bias-corrected models



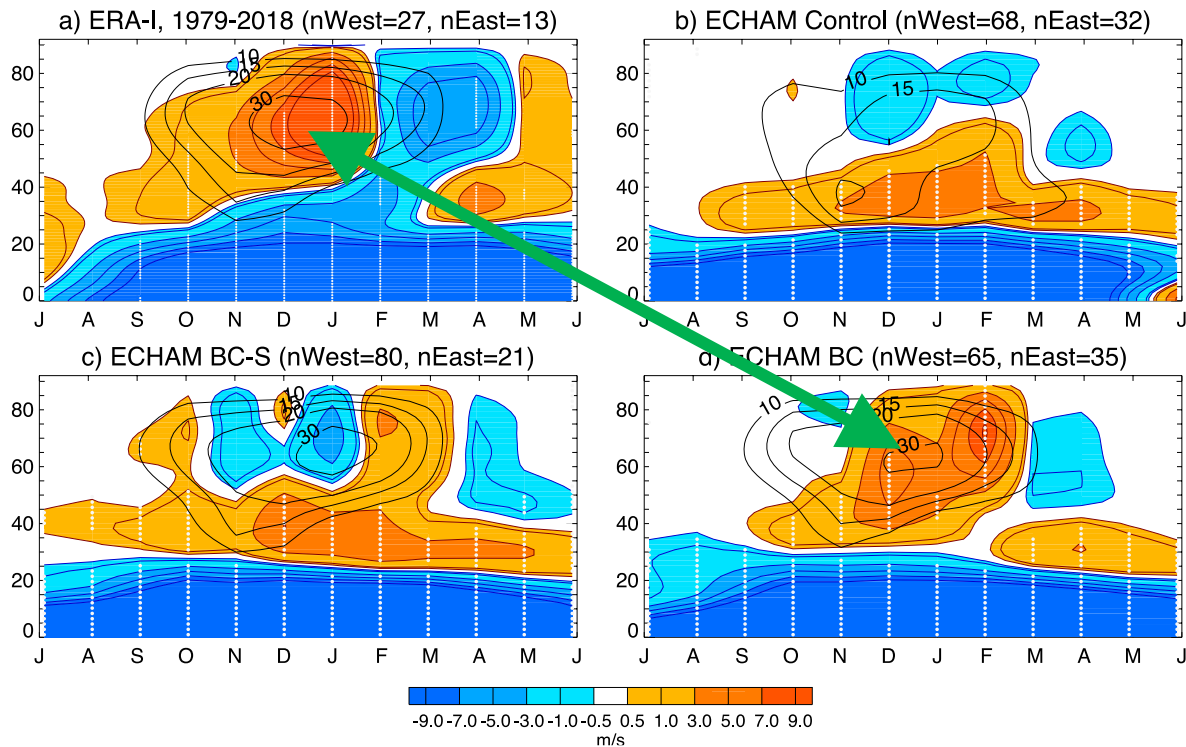
- ✓ QBO survived bias correction but the period became too long
- ✓ Affects number of years in each phase composite



Extratropical response to QBO

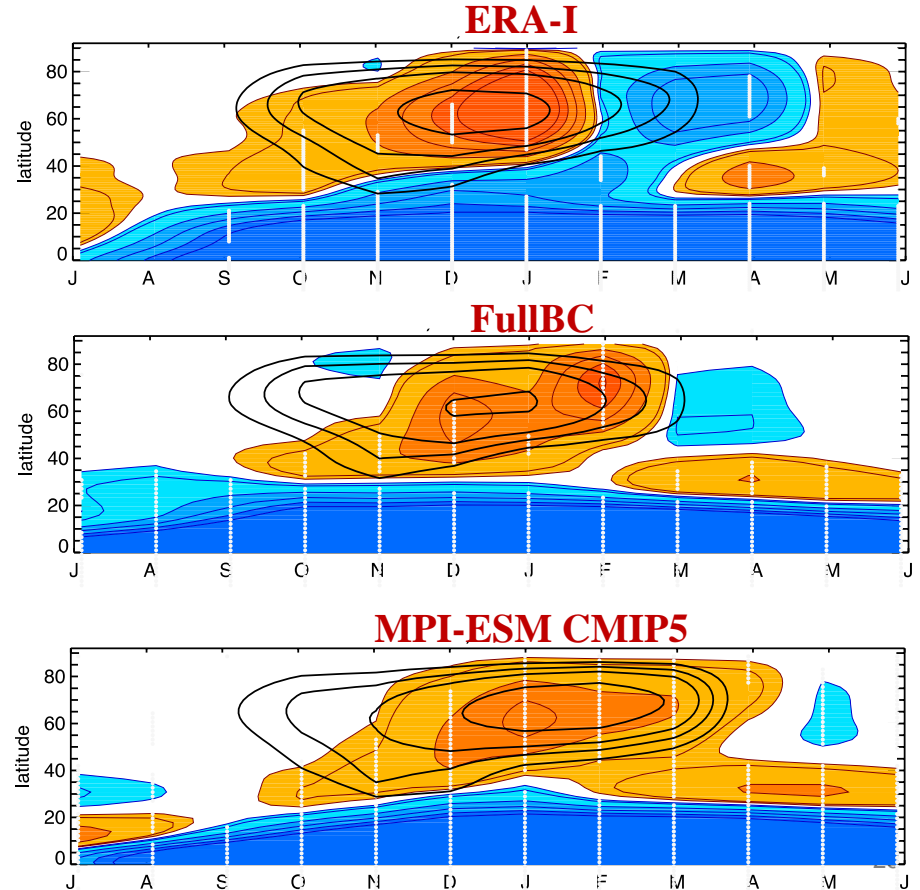
- ✓ CTRL has weak response to QBO
- ✓ StratBC has much improved stratospheric jet but not so much improved response to QBO
- ✓ FullBC has both improved stratospheric jet and realistic response to QBO

10-hPa U difference between QBO-W and QBO-E



Extratropical response to QBO

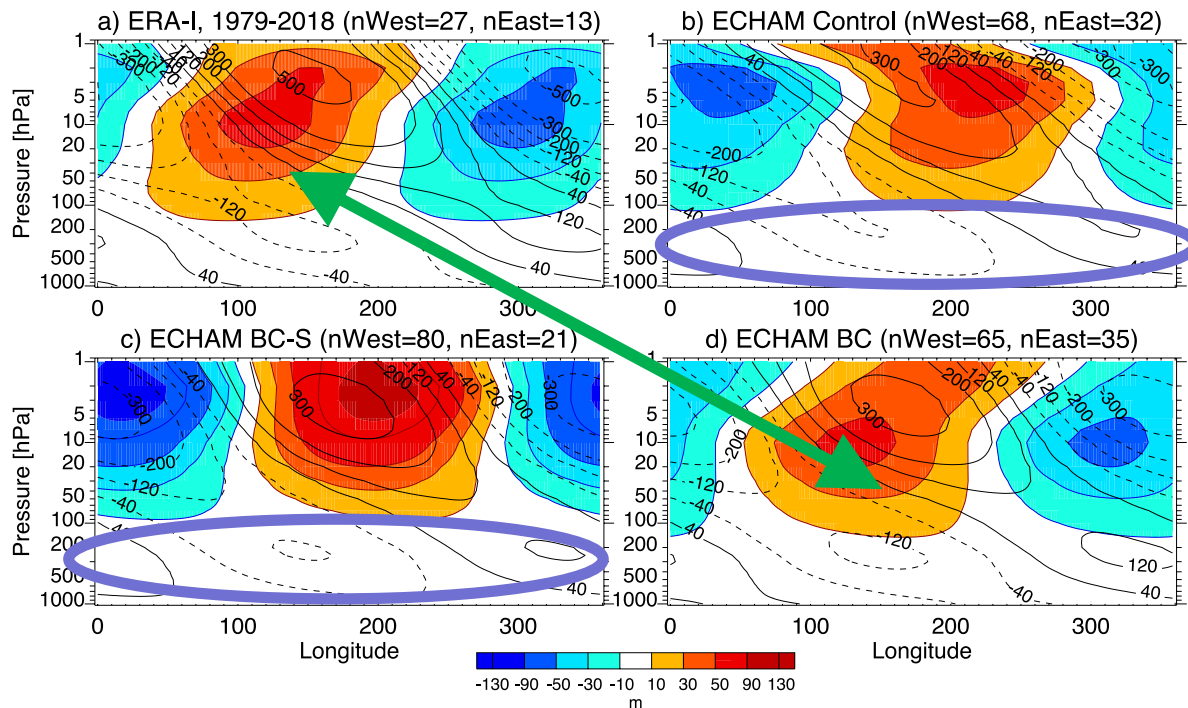
- ✓ FullBC has a realistic response to QBO but so has a best tuned version of the same model, MPI-ESM from CMIP5



Stationary waves: bias and response

- ✓ FullBC has realistic *response* of stationary wavenumber 1 to QBO
- ✓ FullBC has realistic magnitude of climatological wavenumber 1
- ✓ The magnitude of climatological wavenumber 1 in the troposphere is underestimated by factor 1.5-2 in CTRL and StratBC.
- ✓ Unrealistically small tropospheric wave forcing may be less sensitive to QBO-induced changes in wave propagation in the stratosphere (O'Sullivan and Young 1992), leading to weak teleconnections in biased models

Wavenumber 1 difference between QBO-W and QBO-E



Summary

- Bias correction technique is a great research tool for studying dependence of processes on background climatology
 - Will be applied to understand other teleconnections
- Eurasian snow cover weakens polar vortex and can induce a weak negative NAM in the troposphere in December – early January but not later.
 - No evidence that removing model biases can reconcile models and observations. Is observed negative NAM response to October snow robust?
- Differences in stratosphere-troposphere coupling between different climatologies might be explained by different preconditioning in the troposphere
- QBO teleconnections to NH stratosphere is greatly improved by alleviating biases
- Biases in both stratospheric circulation and tropospheric waves likely negatively contribute to simulated QBO teleconnections



Additional slides



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EP-flux

