The Downward Propagation of Split and Displacement Type SSWs in an Idealised Model

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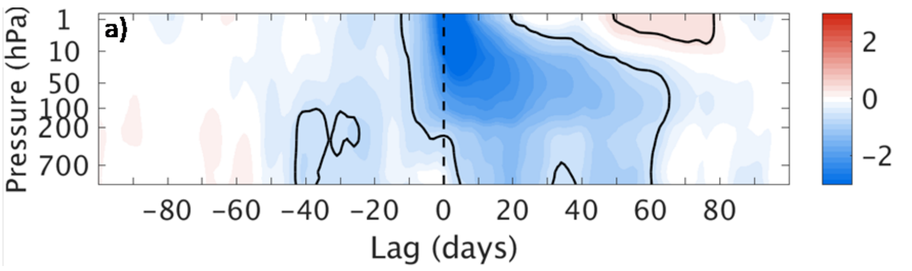
Background

Motivation

Some SSWs have a near-surface influence (as we all now know!)



NAM composite over 22 SSWs in our idealised model

Studies have applied zonally-symmetric thermal forcing to the stratosphere to examine tropospheric response (e.g., Polvani and Kushner 2002; Kushner and Polvani 2004)

Most recently, White et al. (2020) applied such a forcing for just a few days to simulate the sudden nature of an SSW

However, what about splits and displacements which are inherently asymmetric?

- Indeed, studies debate whether splits and displacements do have different tropospheric responses (e.g., Mitchell et al. 2013; Maycock and Hitchcock 2015)

We here apply zonally-asymmetric thermal forcing to the stratosphere to examine the influence of the two SSW types

Background

Motivation

We ask two questions:

1) **Is there a difference between the impacts of splits and displacement SSWs on the troposphere?**

2) **Does the phasing of the vortex anomalies matter for the tropospheric response?**

- We here present some preliminary results...

Model

Model of an Idealised Moist Atmosphere (MiMA)

We use:

-MiMA (**M**odel of an **I**dealised **M**oist **A**tmosphere; Jucker and Gerber 2017) – primitive-equation dynamical core plus moisture and precipitation (no clouds)

More realistic stratospheric circulation than that used in previous idealized modelling studies (full radiation scheme with interactive water vapour and ozone climatology)

For our study:

- Run with 40 vertical layers and with model top at 0.01hPa (70km), and T42 horizontal resolution

- Setup following Garfinkel et al. (2020) with q-fluxes, land/sea contrasts and realistic topography

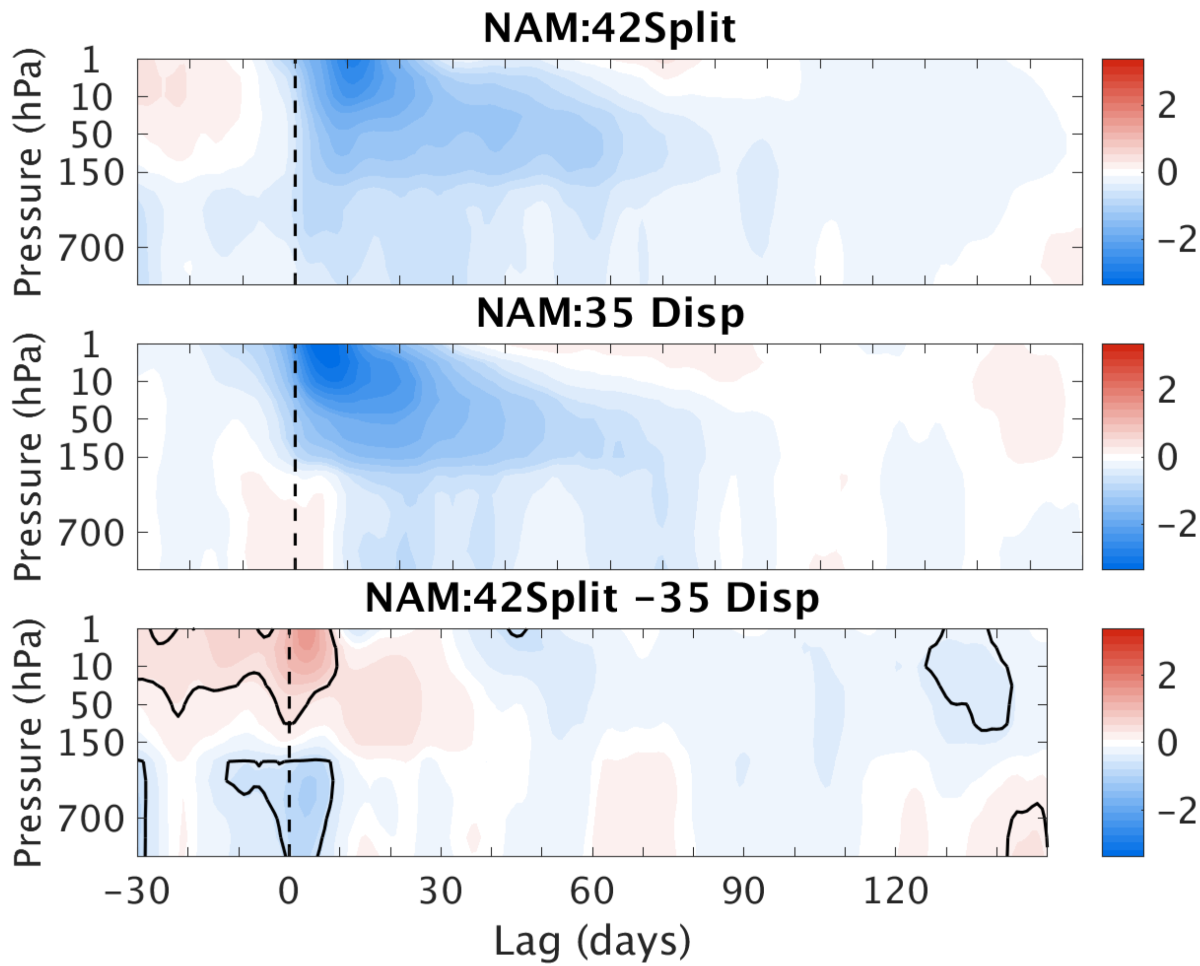
-In a previous study (White et al. 2020), we applied zonally-symmetric thermal torques to the stratosphere and found that the tropospheric response was generic to a lower-stratospheric warming and that initial Rossby-wave forcing was unimportant at long lags

Model

Control (CTRL) Runs

- 3x Free-running control (**CTRL**) each for 50 years
  → 42 Splits
  → 35 Displacements
  Using Seviour et al. (2013) algorithm for identifying such SSWs

- No difference between splits and disp aside from at negative lags (precursors) and within first 10 days. Disp appear to be stronger in stratosphere, at least initially



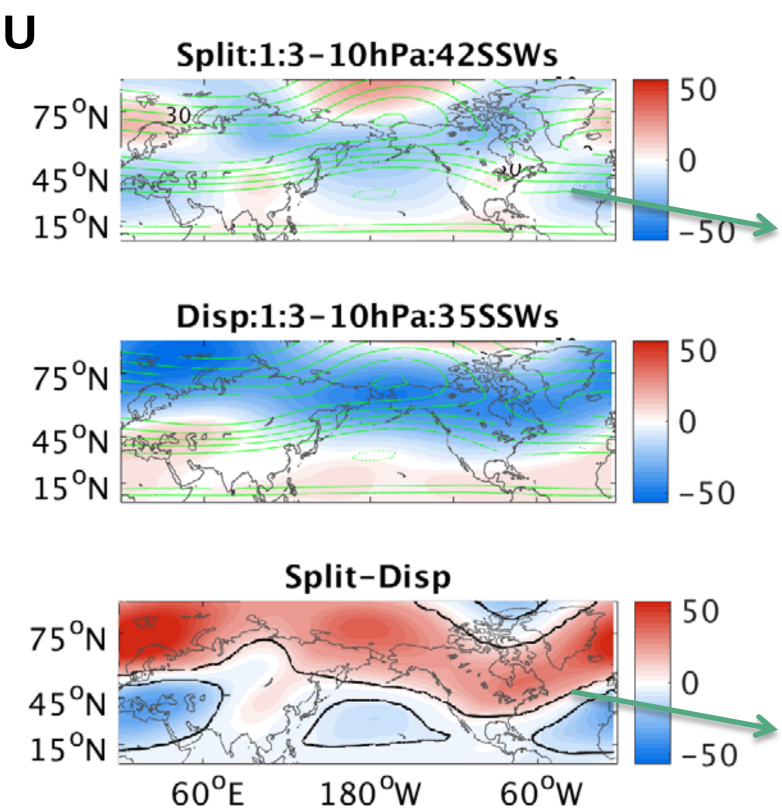
- We only keep one CTRL (that which was used in White et al. 2020) and spin-off a series of perturbation experiments (PTRB) every Jan 1st

Model

Control (CTRL) Runs

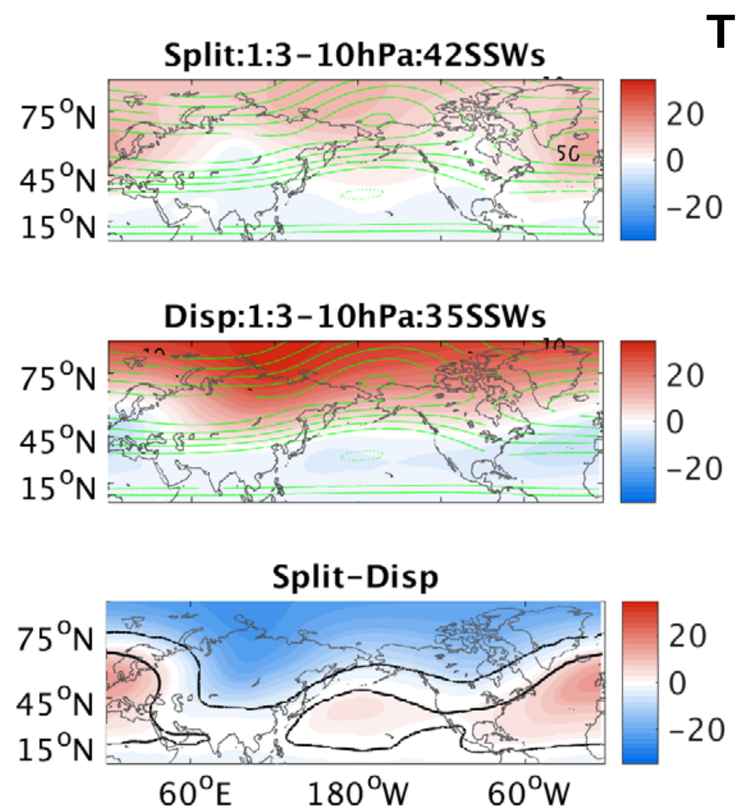
10hPa Split (top), Disp (middle) and S-D (bottom)
Lags 1-3

- For Splits: T peaks at 0E and 180E
- For Disp, T peaks at around 90-180E
- Disp stronger than Split (agrees with NAM)



Green contours represent climatological U at given level in all future plots

Black contour represents stat sig difference between S and D at 95% level



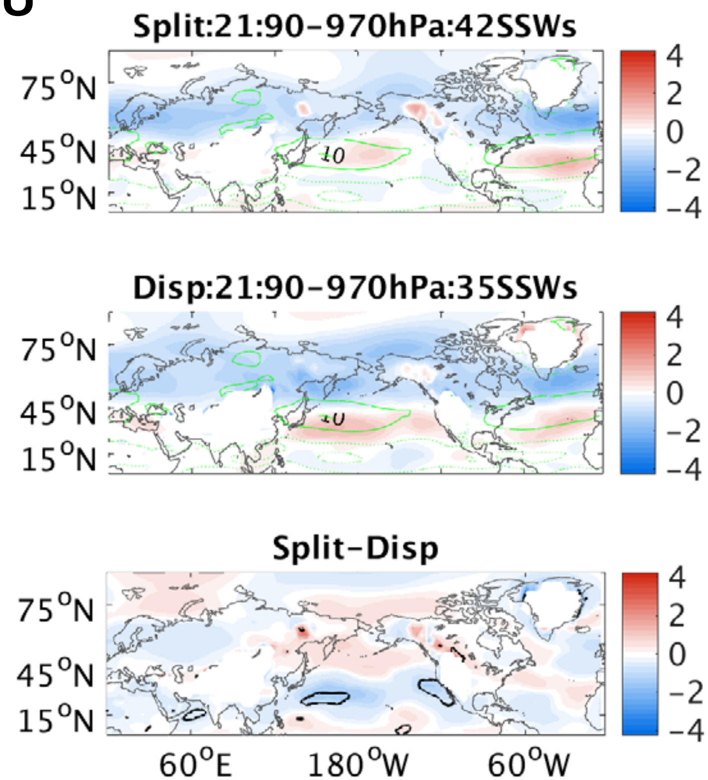
Model

Control (CTRL) Runs

970hPa Split (top), Disp (middle) and S-D (bottom)
Lags 21-90

- Both show a somewhat zonally-symmetric near-surface U response with *jet shift* in the North Atlantic, and *jet pulsing* in the North Pacific (NB: this projects onto the 1st EOF in MiMA, which is more zonally-symmetric than in reanalysis)
- Overall, little difference between S+D, aside from slightly stronger North-Pacific response in Disp

U



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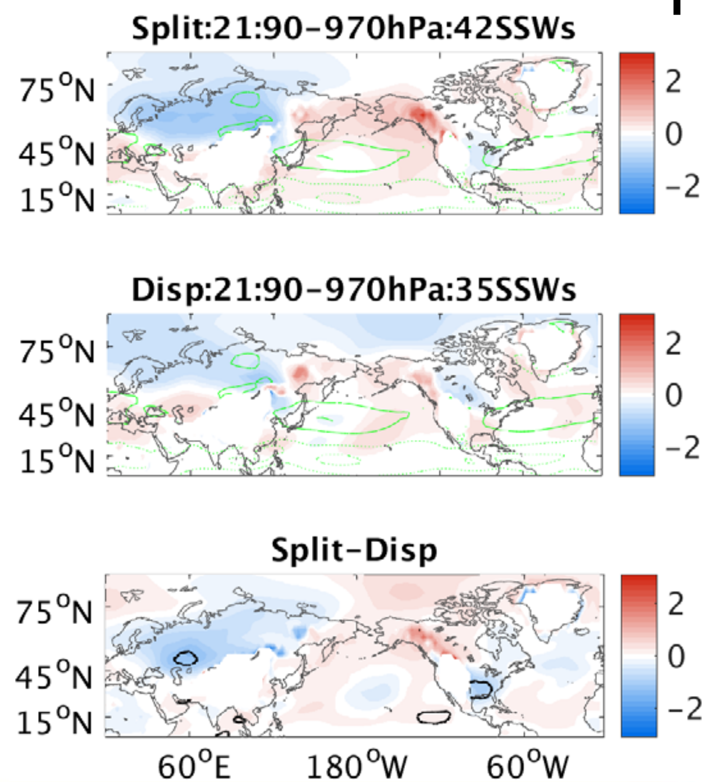


Model

Wave-2 Perturbation (PTRB) Experiments

- Every Jan 1st in CTRL (i.e., different initial conditions), impose zonally-asymmetric thermal forcing (Q_{ZA}) centered at 60N, for only 3 days

- Also include a weaker zonally-symmetric thermal forcing (Q_{ZM}) further poleward so that anomalies project onto NAM

- Apply from TOA to 60hPa, and decrease linearly down to 150hPa

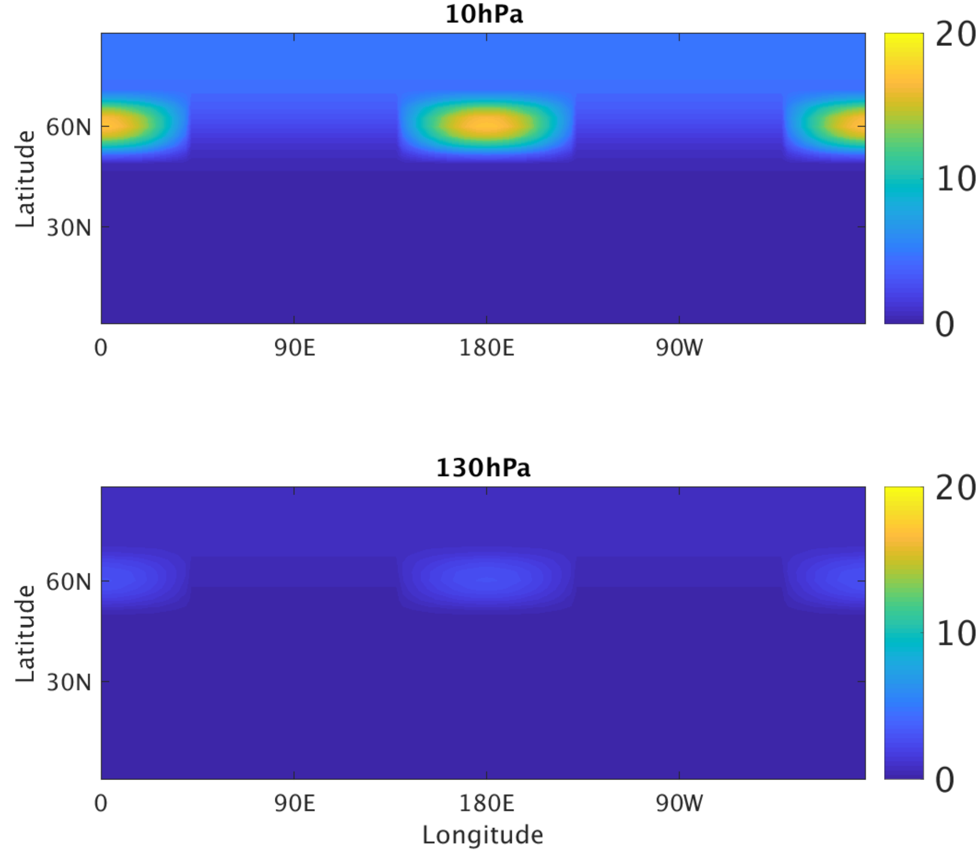
-Vary wavenumber of forcing (k=1,2)

- Vary phase (i.e., lon = lon of first ridge east of 0^o)

-Vary Q_{ZM} (only show = 5K here) and Q_{ZA} (0, 10, 15, 25 K day^{-1})

- Compare surface impact with CTRL splits and displacements

Example Wave-2 Forcing



Q_{ZM}=5K day^{-1}, Q_{ZA}=15K day^{-1}
lon=0E=180E

-NB: Q_{ZA}=0K day^{-1} is just a zonal-mean forcing as was presented in White et al. (2020)

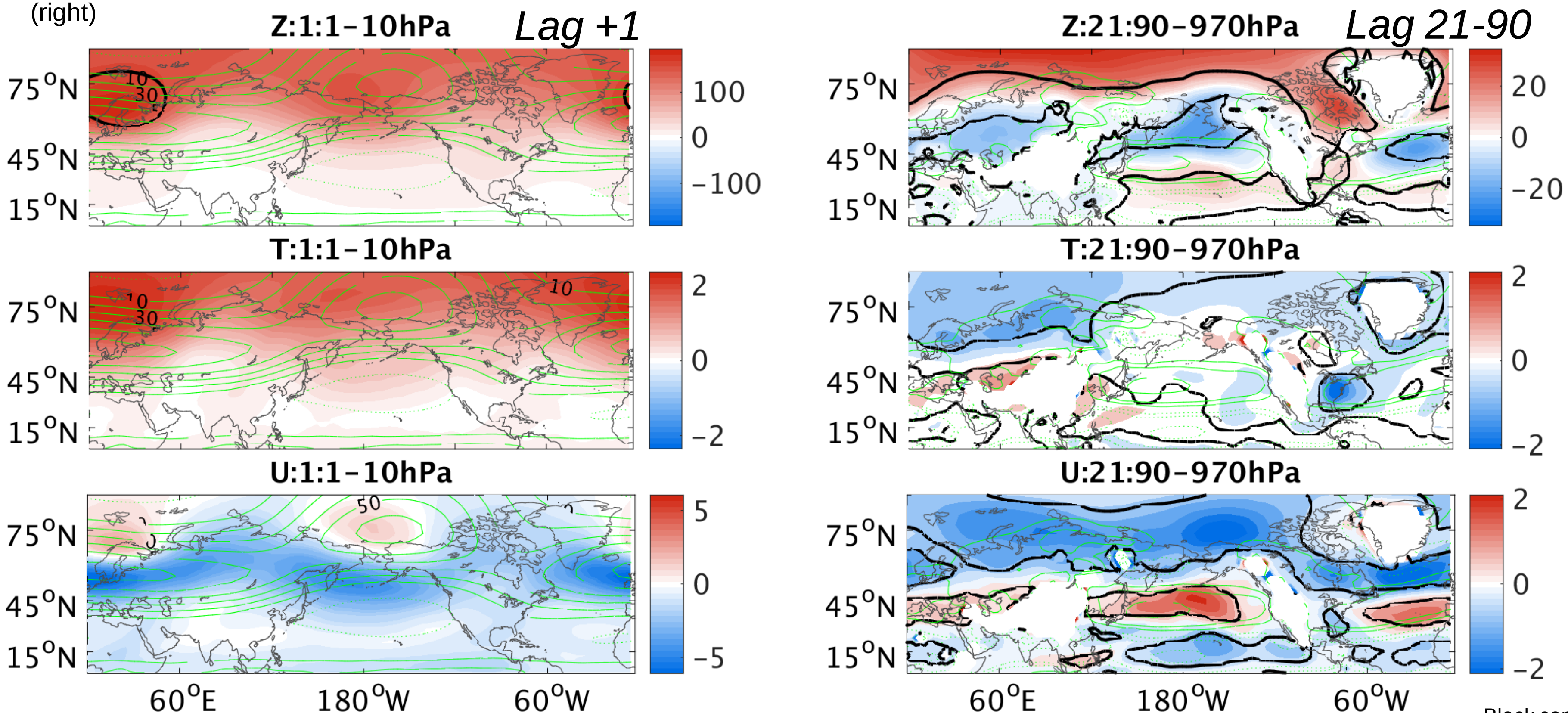
Model

Wave-2 Perturbation (PTRB) Experiments

Z (top), T (middle), U (bottom) at 10hPa (left) and 970hPa (right)

QZM=5,QZA=15, lon=0E=180E,

Lag +1 *Lag 21-90*



Black contour represents stat sig difference from zero at 95% level (different to before)

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-Double-basin response similar to in CTRL Splits (projects onto 1st EOF); jet shift in NA, jet pulsing in NP

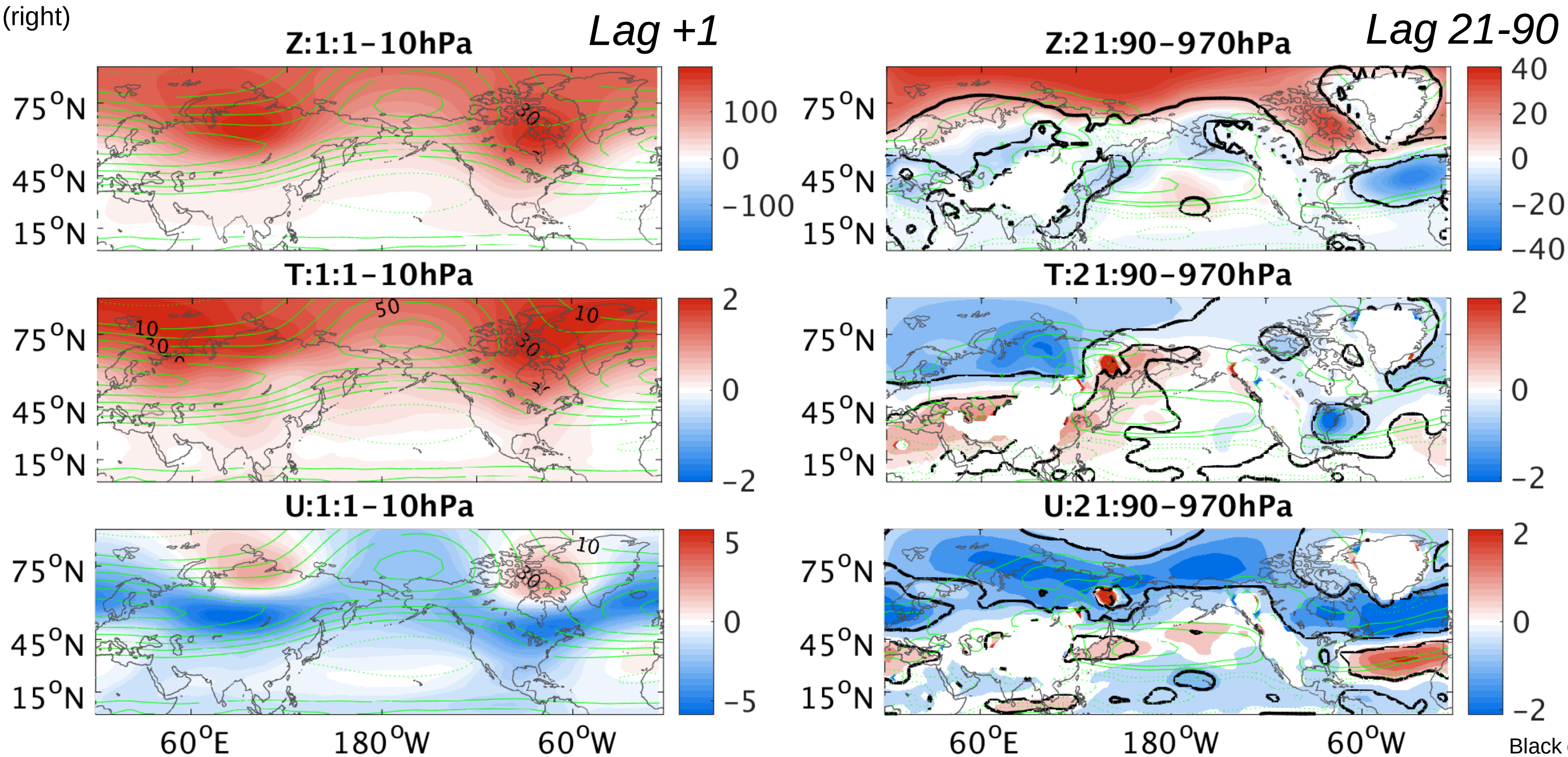
- Cooling over Northern Europe, warming further equatorward

Model

Wave-2 Perturbation (PTRB) Experiments

Z (top), T (middle), U (bottom) at 10hPa (left) and 970hPa (right)

QZM=5,QZA=15, lon=90E=270E,



Black contour represents stat sig difference from zero at 95% level (different to before)

- If warming is moved to 90E, then U>0 anomalies are slightly weaker in NP (small region of stat sig at 95% level when difference is taken; not shown)

Model

Wave-1 Perturbation (PTRB) Experiments

- Every Jan 1st in CTRL (i.e., different initial conditions), impose zonally-asymmetric thermal forcing (Q_{ZA}) centered at 60N, for only 3 days

- Also include a weaker zonally-symmetric thermal forcing (Q_{ZM}) further poleward so that anomalies project onto NAM

- Apply from TOA to 60hPa, and decrease linearly down to 150hPa

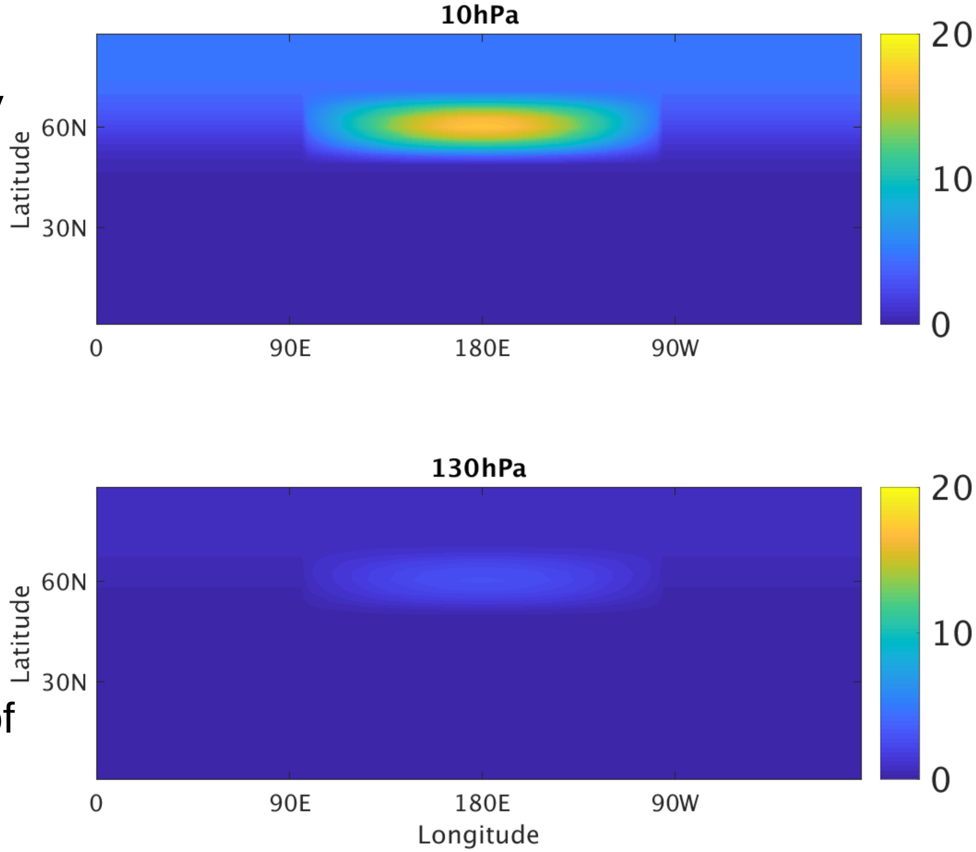
-Vary wavenumber of forcing (k=1,2)

- Vary phase (i.e., lon = lon of first ridge east of 0º)

- Vary Q_{ZM} (only show = 5K here) and Q_{ZA} (0, 10, 15, 25 K day^{-1})

- Compare surface impact with CTRL displacements and with PTRB wave-2 before

Example Wave-1 Forcing



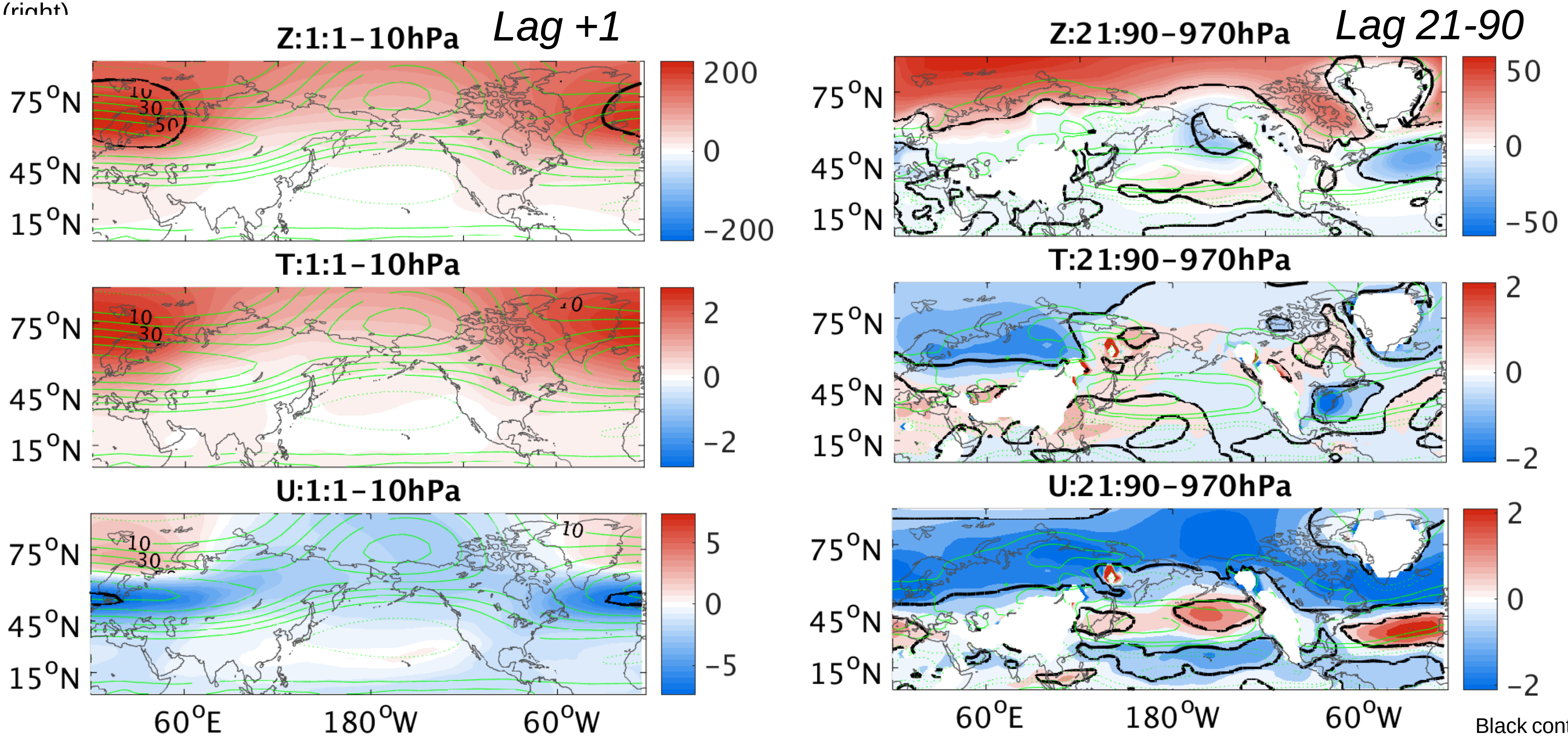
Q_{ZM}=5K day^{-1}, Q_{ZA}=15K day^{-1} lon=180E

Model

Wave-1 Perturbation (PTRB) Experiments

Z (top), T (middle), U (bottom) at 10hPa (left) and 970hPa (right)

QZM=5,QZA=15, lon=0E,



Black contour represents stat sig difference from zero at 95% level (different to before)

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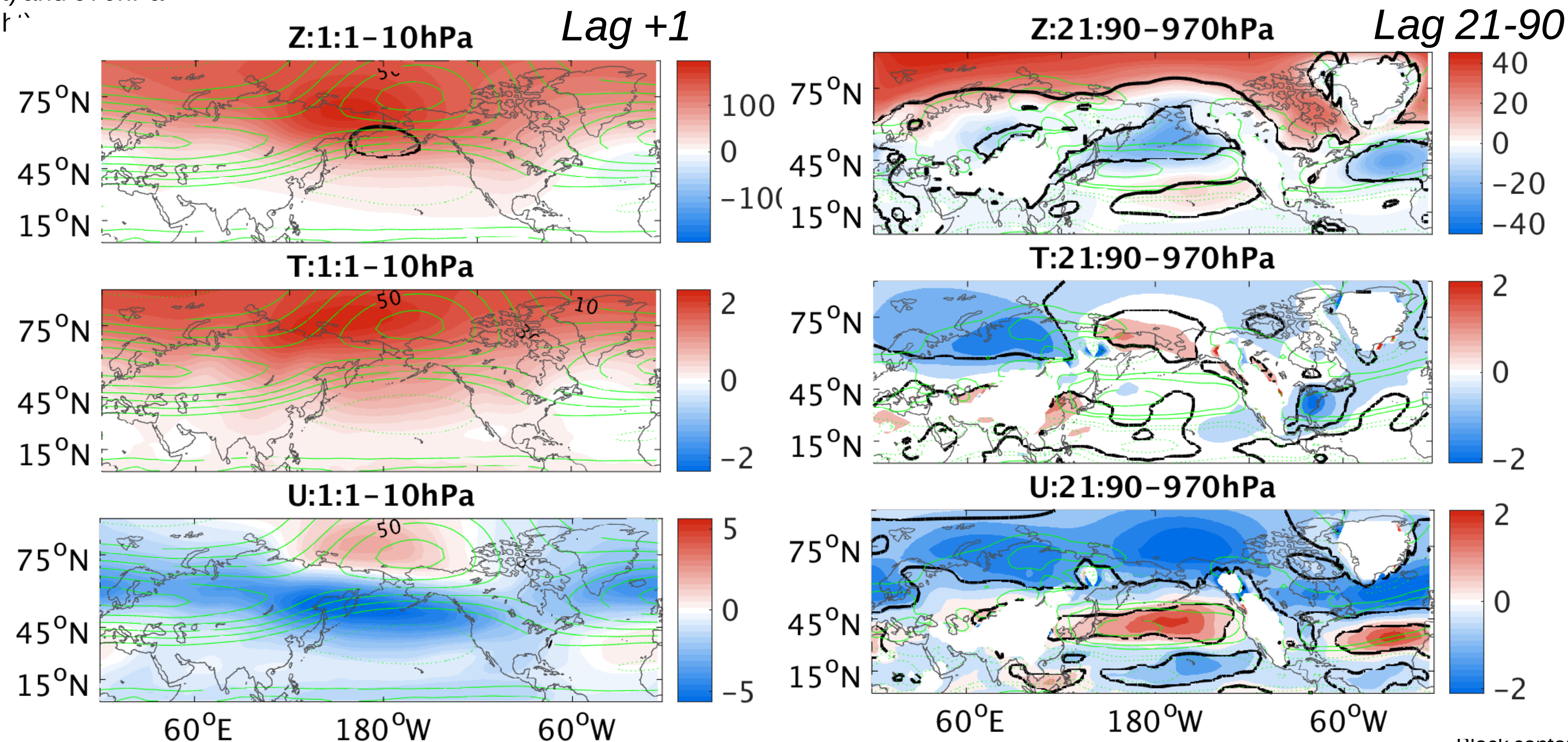
- Qualitatively similar surface response to Wave-2, but with slightly larger magnitudes

Model

Wave-1 Perturbation (PTRB) Experiments

Z (top), T (middle), U (bottom) at 10hPa (left) and 970hPa (rigł ˋ`

QZM=5,QZA=15, lon=180E,



Black contour represents stat sig difference from zero at 95% level (different to before)

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- Very similar response to Wave-1 0E experiment – i.e., location of wave-1 vortex does not appear to matter for tropo response
- Indeed, difference between 0E and 180E runs only shows a slightly stat sig stronger jet shift in 0E run (not shown)

Model

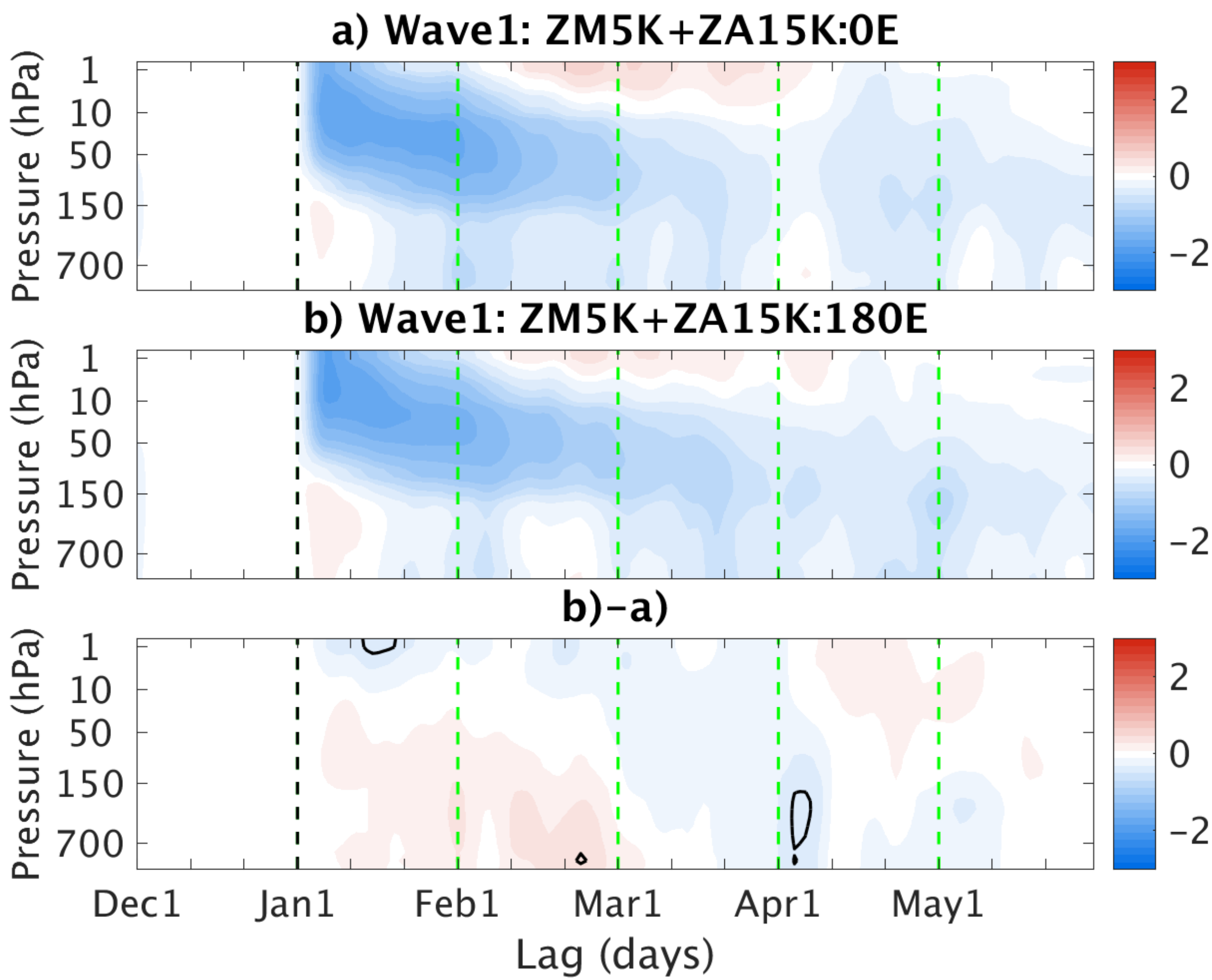
Wave-1 Perturbation (PTRB) Experiments

NAM for 2 different Wave-1 experiments (top and middle) and their difference (bottom)

- Shifting wave-1 vortex from 0E to 180E does not yield a sig difference in troposphere (slightly stronger surface response when at 0E, but insig)

- NB: The extended NAM compared to CTRL SSWs is either due to the final warming date changing (i.e., the second peak in NAM in Apri-May) and/or longer persistence timescales in T42 runs (NAM timescales are shortened in our T85 runs)

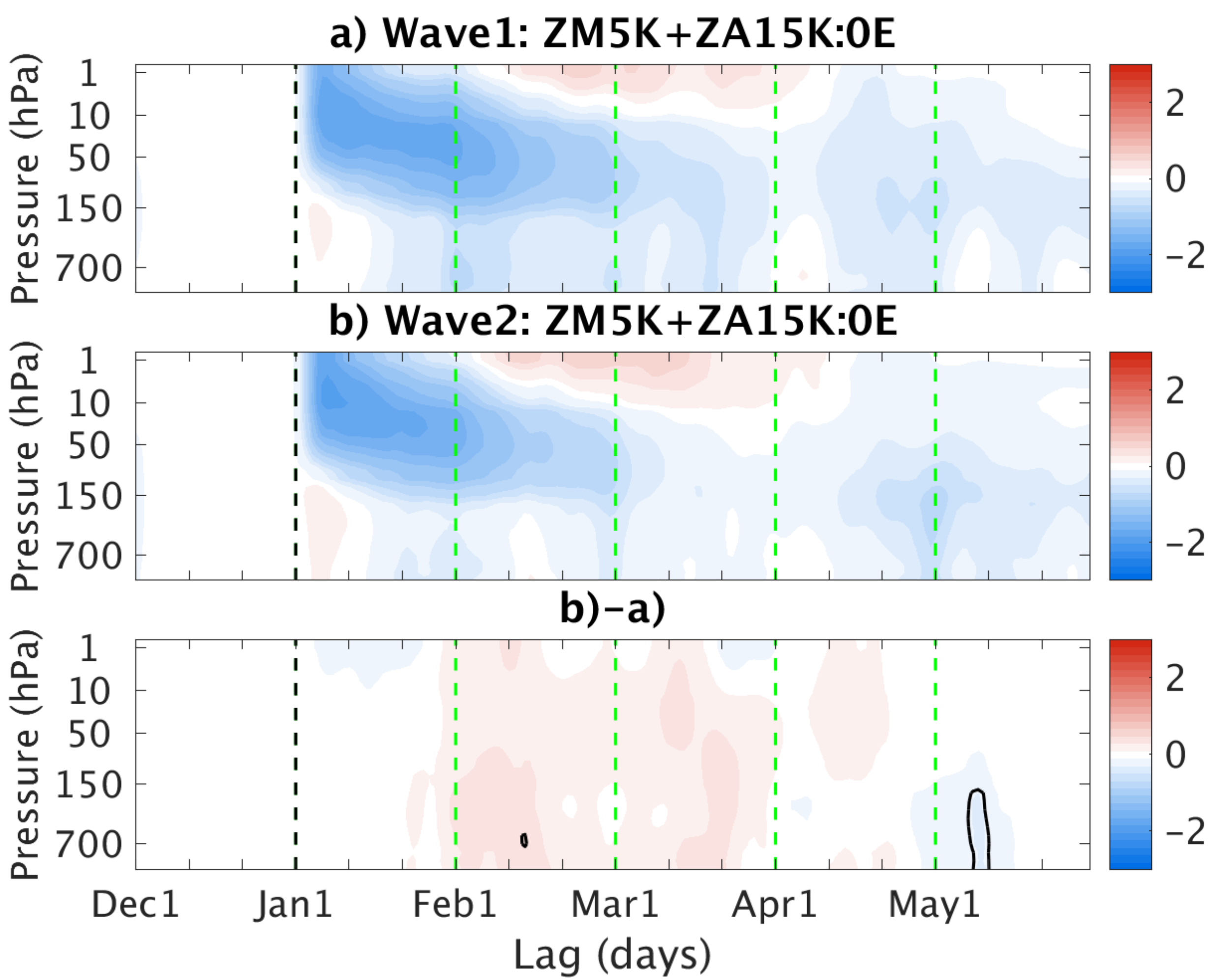
- Also similar result in near-surface regional plots



Model

Wave-1 vs Wave-2 Perturbation (PTRB) Experiments

NAM for a Wave-1 and Wave-2 experiment (top and middle) and their difference (bottom)



- No sig difference between wave-1 and wave-2 on troposphere (slightly stronger tropo NAM for wave-1, in agreement with CTRL, but insig)

- Also similar result in near-surface regional plots

Results

Various ZA Experiments: Q_{ZM} 5 K

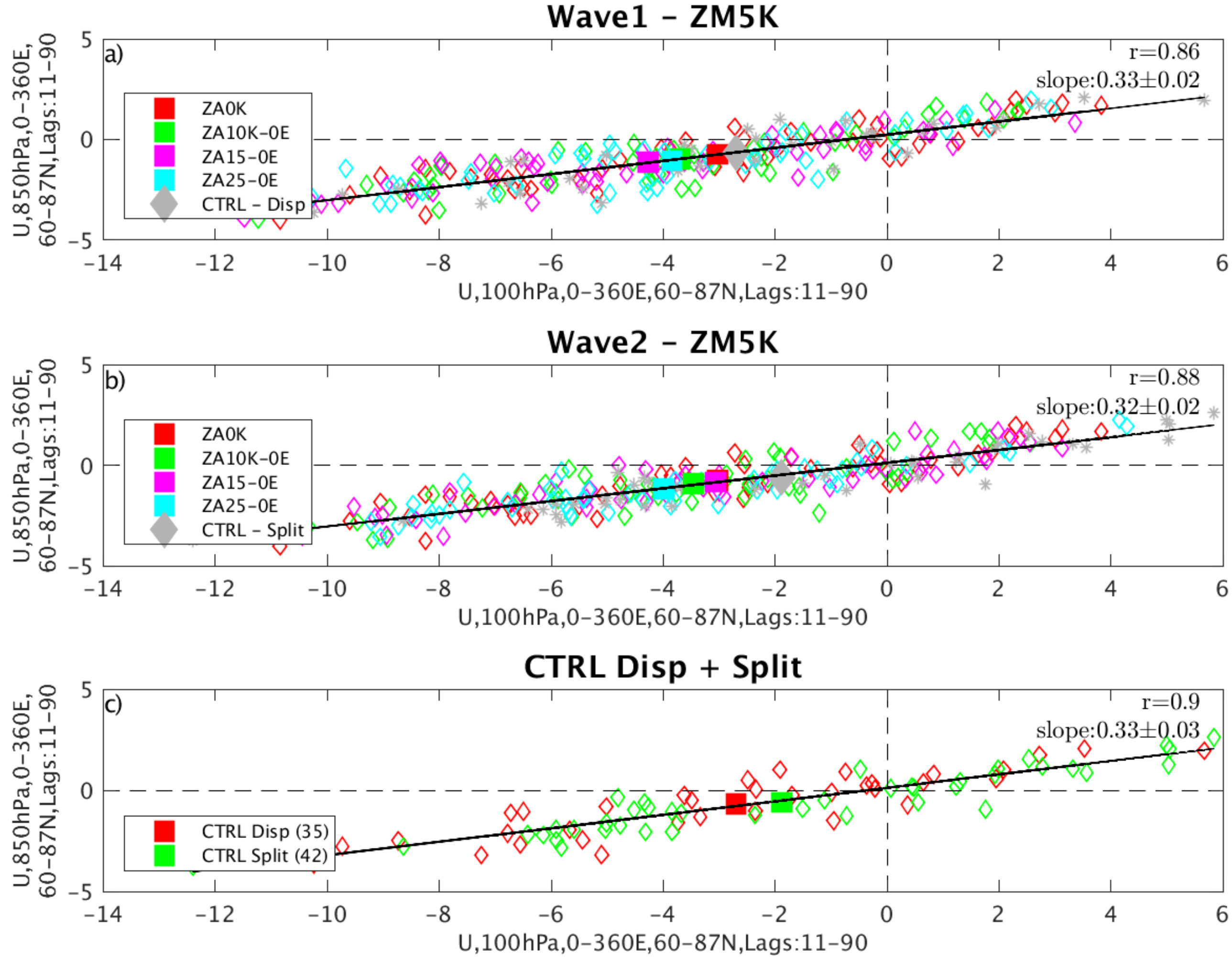
- How does surface respond to different magnitude Q_{ZA} forcings?

- ZM forcing (ZM=5 K) with varying ZA forcing (ZA=10,15,25 K) and lon=0E

- More negative U in lower strato gives rise to more negative near-surface U

- Strong linear relationship in all three panels

- Slopes of regression lines almost identical between CTRL and PTRB (no sig difference)



In each panel, separate regression lines are shown if in a,b) the CTRL SSWs have a stat sig different regression line compared to the PTRB SSWs, and if in c), the CTRL Disp and Split regression lines are stat sig different

Summary

- Wave-1 and Wave-2 forced SSWs (akin to displacements and splits) do not appear to have a large difference in their surface impact → tropo response is somewhat generic to wavenumber forcing

-Further, phasing of vortex anomalies do not seemingly matter for the downward impact of splits or displacements with only slight differences over the North Pacific

- Linear relationship between lower-stratospheric anomalies and near-surface anomalies at positive lags still evident using ZA forcing

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- This is ongoing work and we are currently examining how to better isolate the role of the ZA part of the forcing from the ZM forcing. Note that the ZM forcing is necessary for a projection onto the NAM….hence, we are now switching on the ZM forcing for 3 days, but leaving the ZA forcing on for longer

I. White, C. I. Garfinkel, E. P. Gerber, M. Jucker, and J. Rao:
An examination of the impact of split and displacement sudden stratospheric warmings on the troposphere in an idealised model,
In Prep.