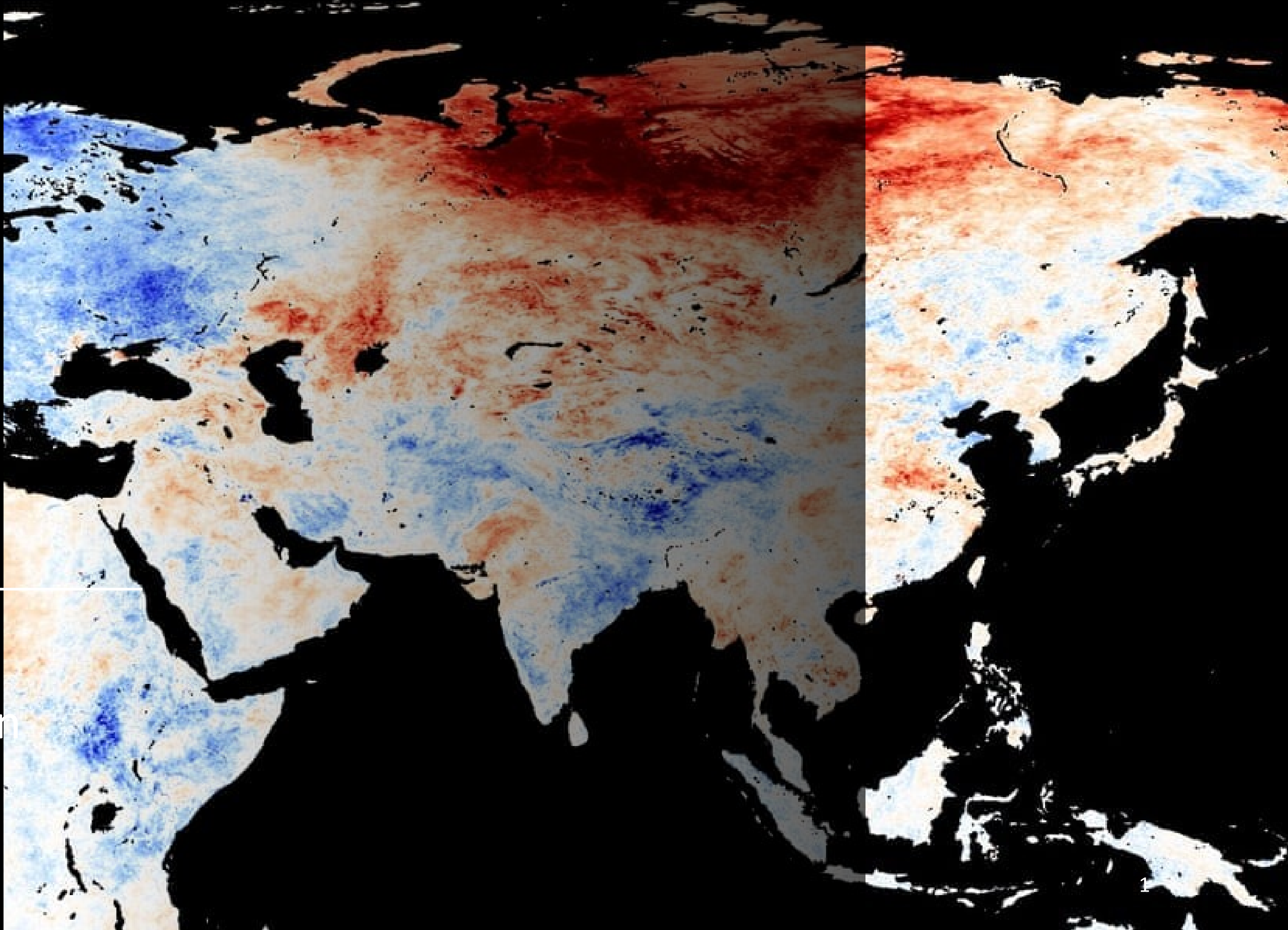
The 2020 Siberian heatwave

In connection to the middle atmosphere in MUAM



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Motivation

- Exceptionally strong and cold stratospheric polar vortex (SPV) in winter 19/20
- Remarkable configuration of wave activity added to strengthening the SPV through the wintermonths
- Strong link between SPV and near-surface circulation
- Large regional temperature and precipitation anomalies

  → <u>Siberian Heatwave Jan-Jun 2020</u>

  → Multiple heat records broken, huge wildfires, melting permafrost…

Wildfires in Siberia

Oil spilling due to broken pipeline → caused by melting permafrost

https://www.bbc.com/

The New York Times

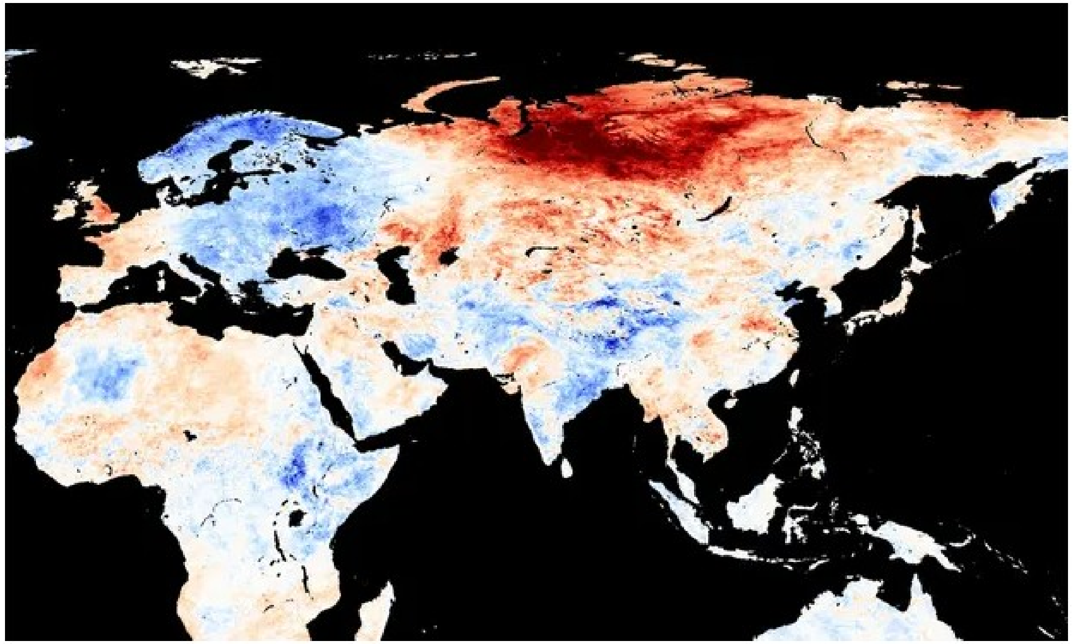
A Historic Heat Wave Roasts Siberia

Wildfires are spreading. The mosquitoes are ravenous. People are shielding their windows from the midnight sun with foil and blankets.

Children playing in a lake outside Verkhoyansk, Russia. The Siberian town has recorded a record high temperature amid a heat wave that is contributing to severe forest fires. Olga Burtseva/Olga Burtseva, via Associated Press

Climate crisis: alarm at record-breaking heatwave in Siberia

Unusually high temperatures in region linked to wildfires, oil spill and moth swarms



▲ A map showing places warmer (red) or cooler (blue) in May than the long-term average. Photograph: Modis/NEO/Nasa

A prolonged heatwave in Siberia is "undoubtedly alarming", climate scientists have said. The freak temperatures have been linked to wildfires, a huge oil spill and a plague of tree-eating moths.

On a global scale, the Siberian heat is helping push the world towards its hottest year on record in 2020, despite a temporary dip in carbon emissions owing to the coronavirus pandemic.

ERA5 T(2m) Anomalies Jan-Jun 2020

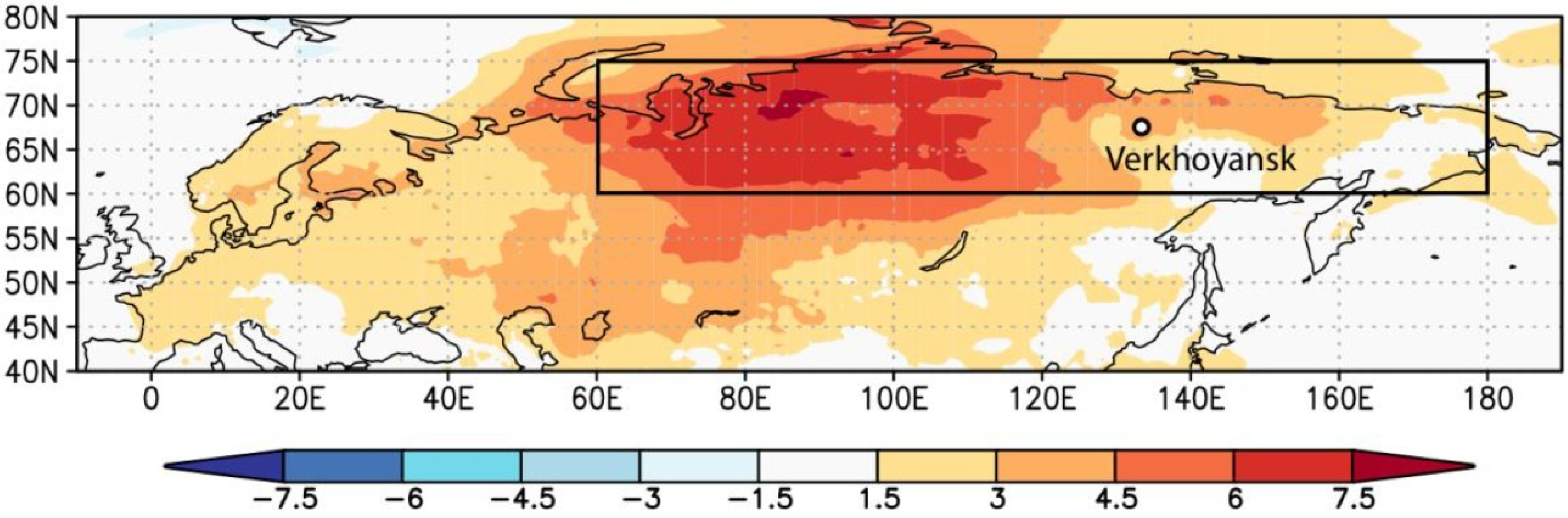


Figure 1: ERA5 near surface temperature (T2m) anomalies [°C] for Jan-Jun 2020. Reference period: 1981-2010. The rectangle represents the study region at 60-75°N, 60-180°E.

https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change/

The New York Times

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Climate crisis: alarm at record-breaking h

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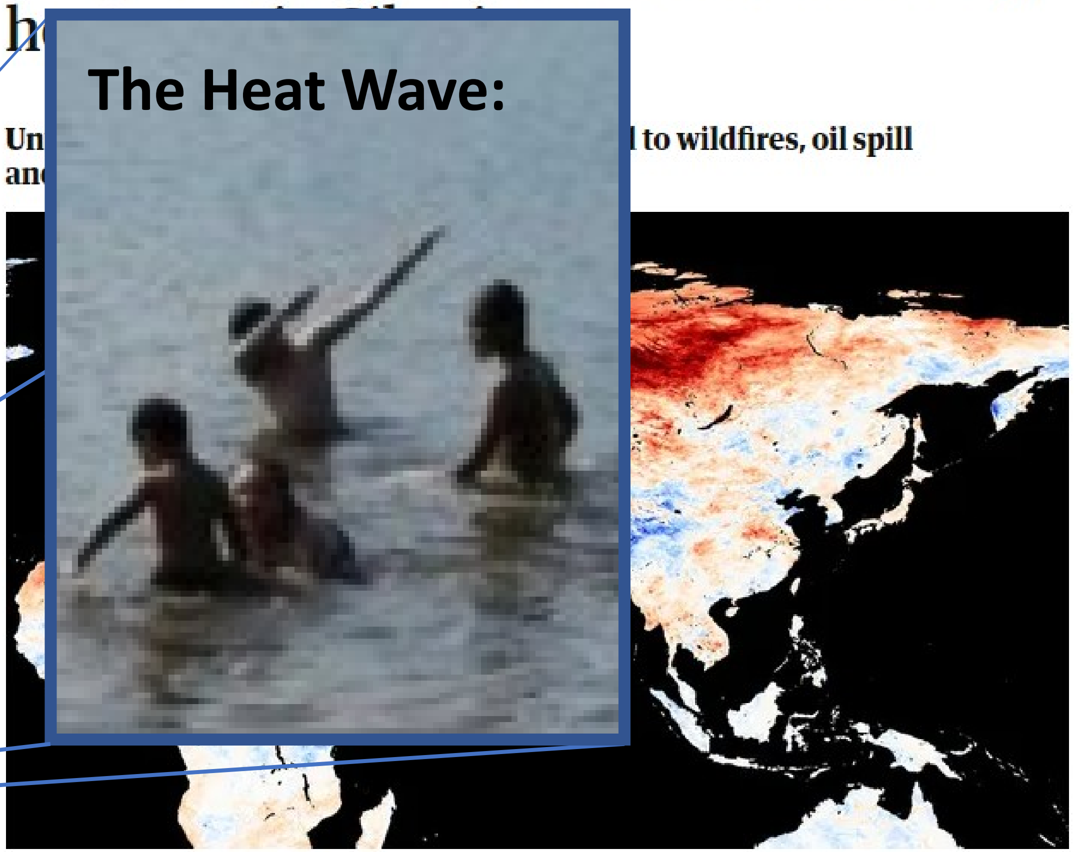

▲ A map showing places warmer (red) or cooler (blue) in May than the long-term average. Photograph: Modis/NEO/Nasa

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On a global scale, the Siberian heat is helping push the world towards its hottest year on record in 2020, despite a temporary dip in carbon emissions owing to the coronavirus pandemic.

Basics – Stratospheric Polar Vortex (SPV)

- Principal stratospheric circulation feature of the polar wintertime
- Strong westerly circulation spanning from roughly 100 to above 1 hPa (16-50km)
- During NH winter, the stratospheric and tropospheric circulations are closely connected

Basics – Stratospheric Polar Vortex (SPV)

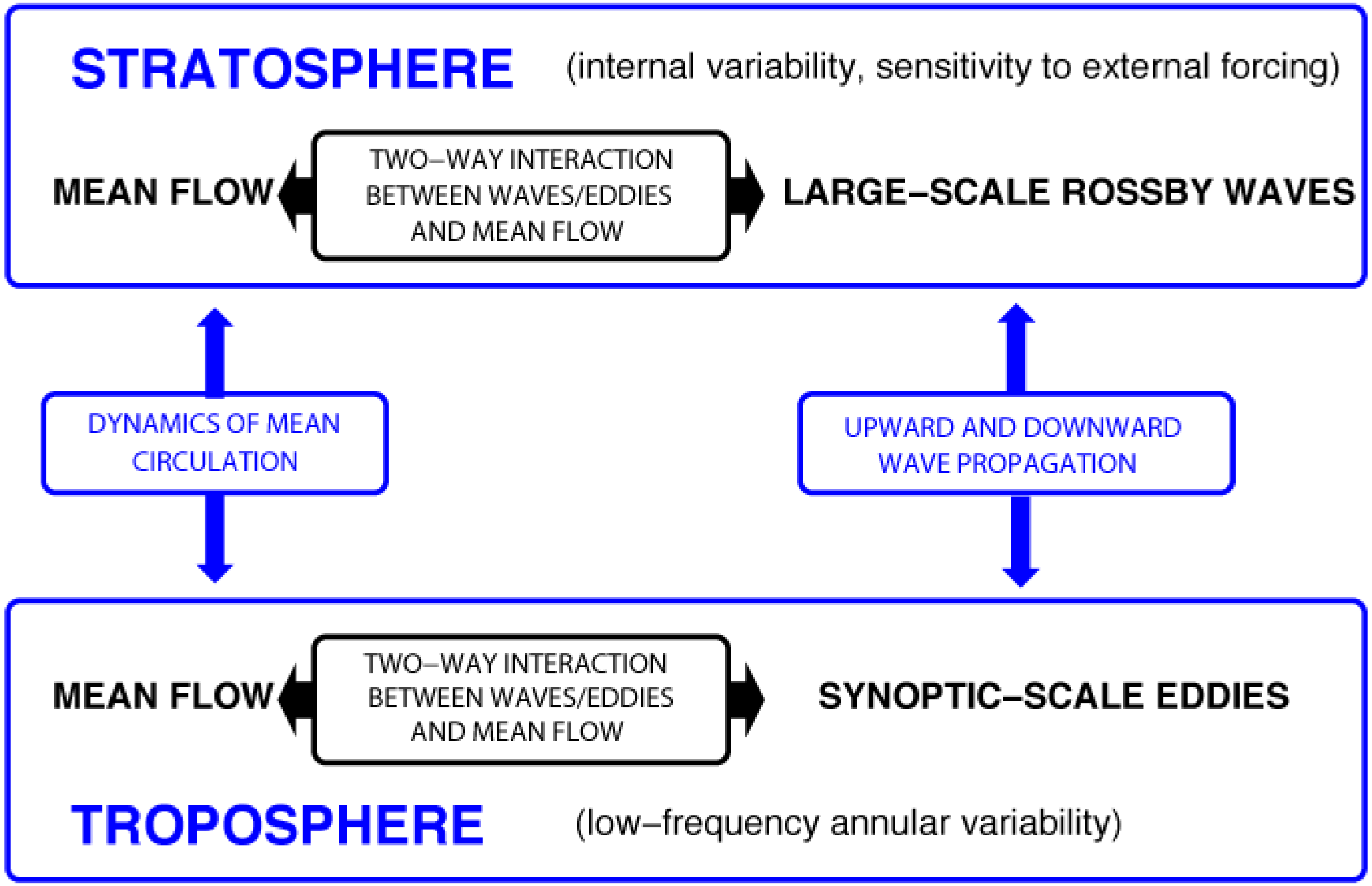
→ Principal stratospheric circulation feature of the polar wintertime

→ Strong westerly circulation spanning from roughly 100 to above 1 hPa (16-50km)

→ During the winter polar night, the polar vortex strengthens and cools via radiative cooling

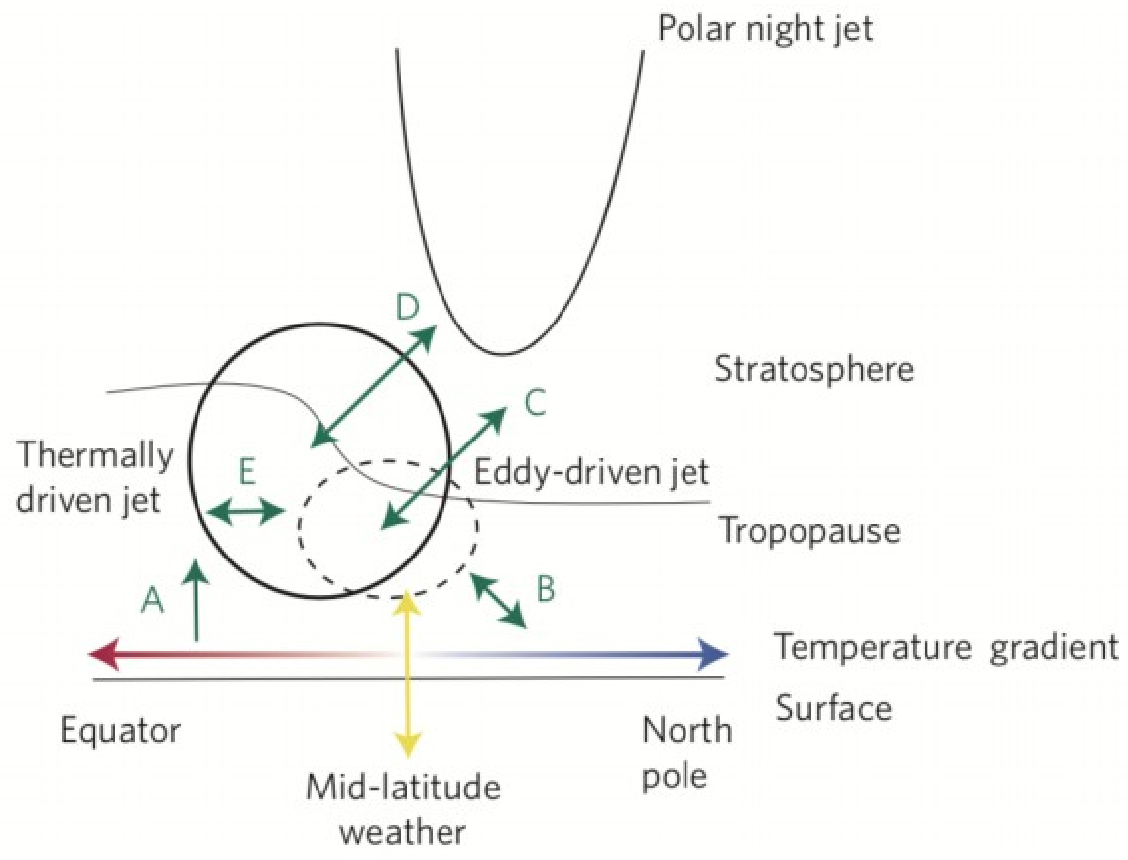
→ The stratospheric and tropospheric circulations are closely connected

Basics – Bottom-Up/Down coupling/interaction



https://www.atmosp.physics.utoronto.ca/SPARC/News25/coupling.html

Basics – Bottom-Up/Down coupling/interaction



https://www.nature.com/articles/ngeo2234
Cohen et al. (2014)

C: Eddy-driven jet affects stratospheric winds via vertical wave propagation <--> Stratospheric winds affect the eddy-driven jet by altering the vertical wave-guide.

D: The thermally driven jet affects stratospheric winds via generation of orographically forced waves <--> Stratospheric winds affect the thermally driven jet by altering the vertical wave guide.

Basics – Bottom-Up/Down coupling/interaction

- Rossby wave propagation out of the troposphere **or** downward reflection of Rossby waves from higher in the stratosphere
- Waves from troposphere propagate vertically into the polar stratosphere
- Breaking waves deposit easterly momentum → weakens the westerly zonal circulation (SPV) → warms the polar stratosphere
- average strength of SPV closely depends on the time-integrated wave driving

Basics – Bottom-Up/Down coupling/interaction

<u>Downward wave coupling events:</u>

→ upward-propagating waves are reflected back from the stratosphere

→dynamically strengthening and cooling of the SPV

- Winters with more downward wave coupling events correspond to winters with stronger SPV
- Downward wave coupling events induce tropospheric circulation patterns consistent with a positive AO (on short time scales)

Basics – Bottom-Up/Down coupling/interaction

<u>Stratospheric Warming:</u>

→ Forced by planetary scale waves which propagate up from the lower atmosphere

→ deceleration or reversal of the westerly mean zonal winds in stratosphere

→ Breakdown or severe weakening of SPV

⬇

→ The easterly winds progress back down through the atmosphere
→ Weakening of the tropospheric westerly winds

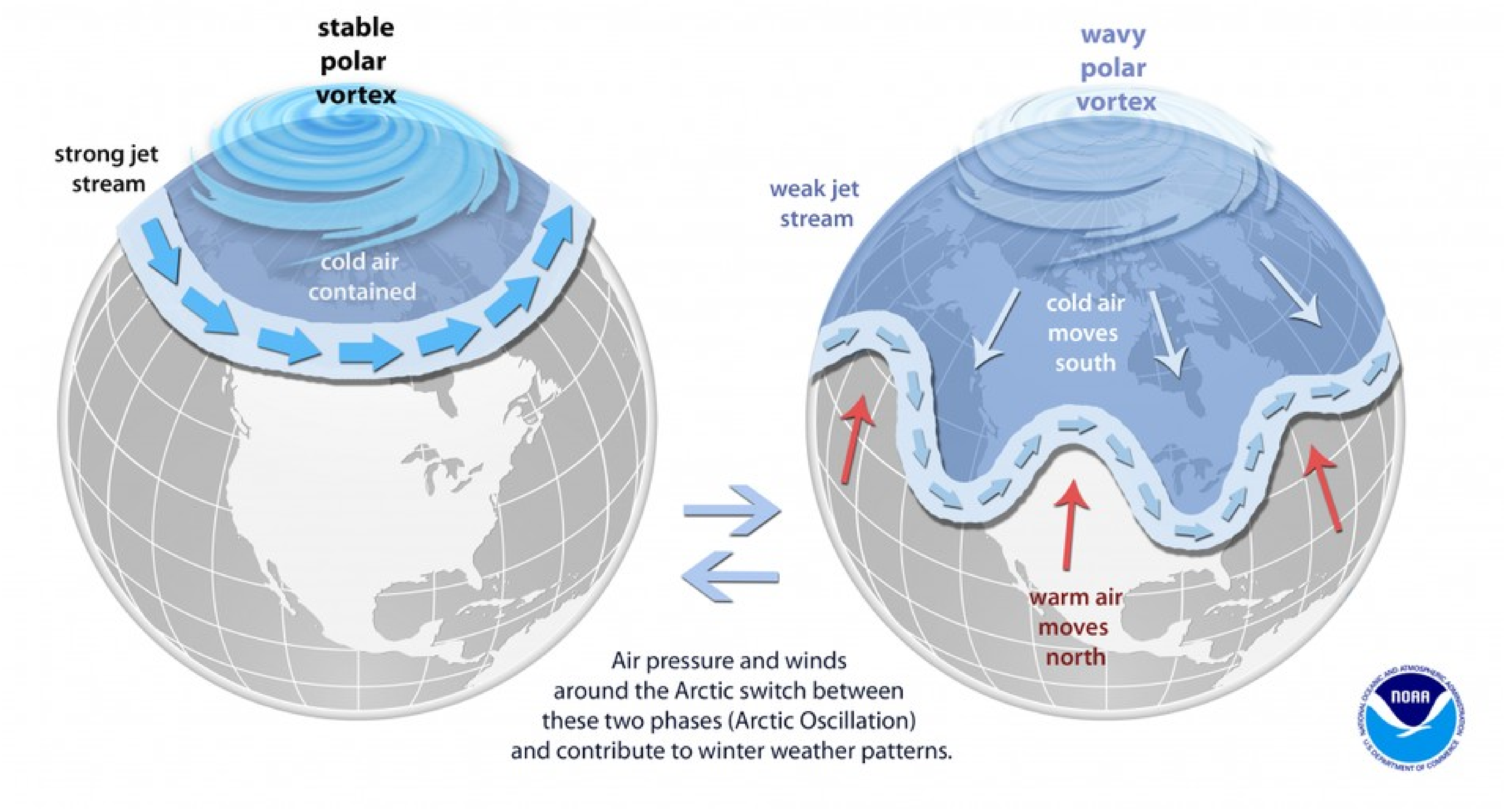
Basics – Eliassen Palm Flux (EPF)

- A vector quantity which determines the eddy heat flux and momentum flux → **diagnostic of wave activity and propagation**

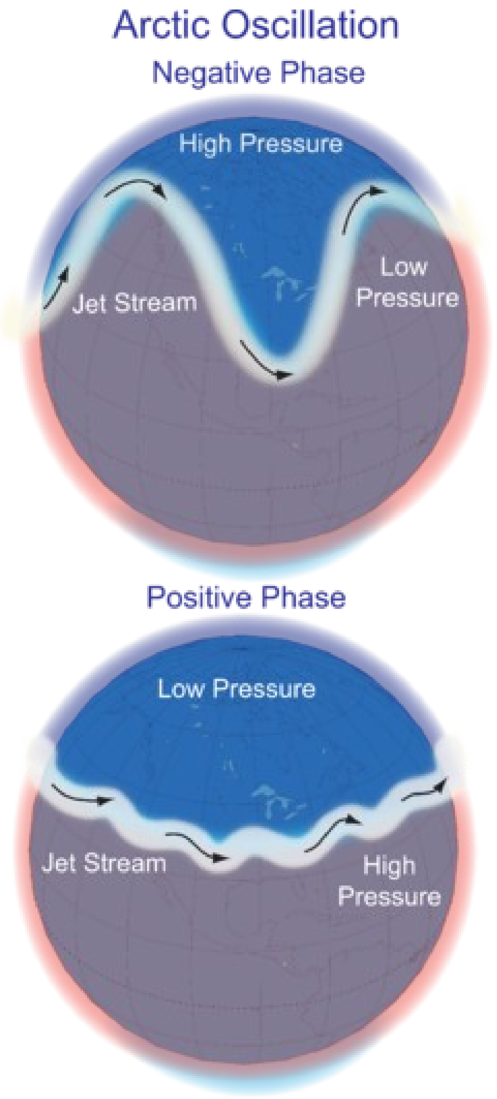
➢ EPF - vector points upward → vertical wave propagation
➢ EPF - vector points horizontal → horizontal wave propagation
➢ EPF - vector points downward → wave reflection

- The divergence of the EPF is more frequently used as a diagnostic tool, as it is proportional to the eddy potential vorticity flux
- More EPF-Divergence = stronger wave activity = accelerated westerly wind

Basics – Bottom-Up/Down coupling/interaction



Basics – Northern Annular Mode (NAM) aka. Arctic Oscillation (AO)



- NAM → characterizes meridional shifts of mass into or out of the polar cap **throughout the atmospheric column**
- AO → characterized by non-seasonal **sea-level pressure** anomalies of Arctic and a region between 37–45° N

Strong SPV

↓

Positive Phase of NAM

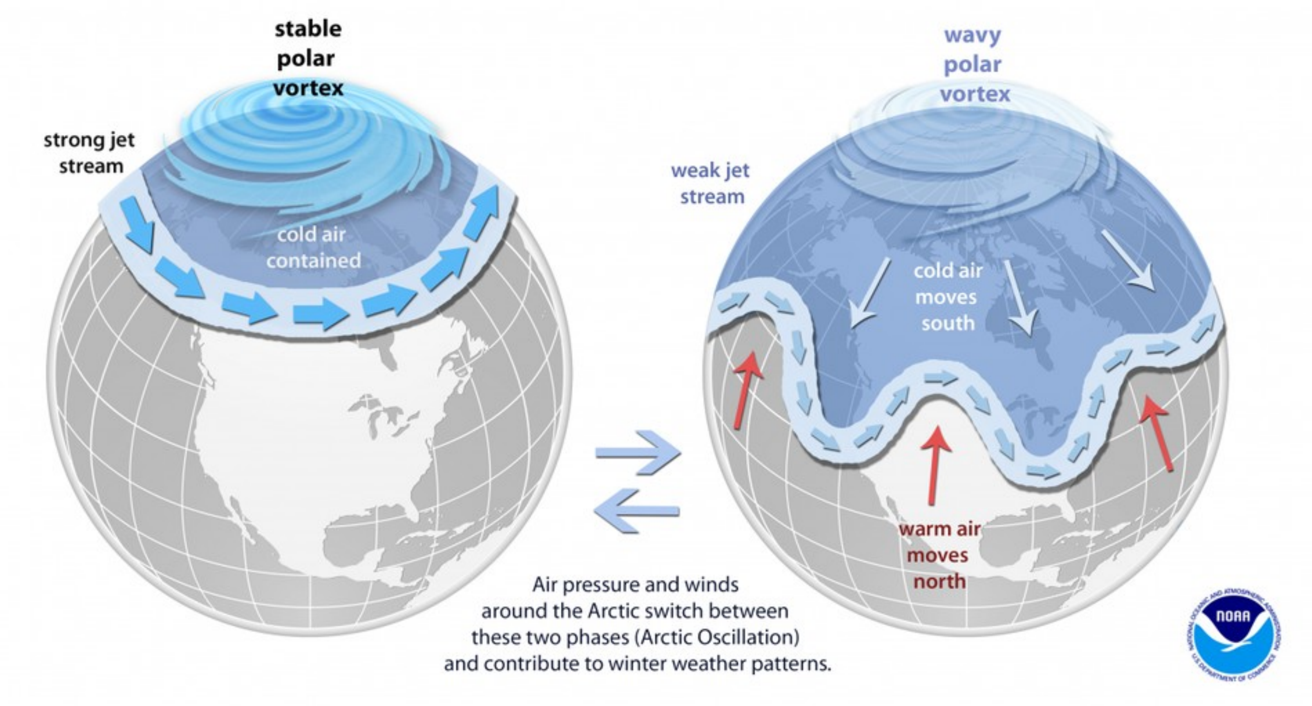
↓

Followed by positive Phase of the AO

And vice versa

NOTE! AO/NAM dont always follow SPV strength

Basics – Bottom-Up/Down coupling/interaction



BUT:

- AO takes 1000hPa geopot. Anomalies into account.

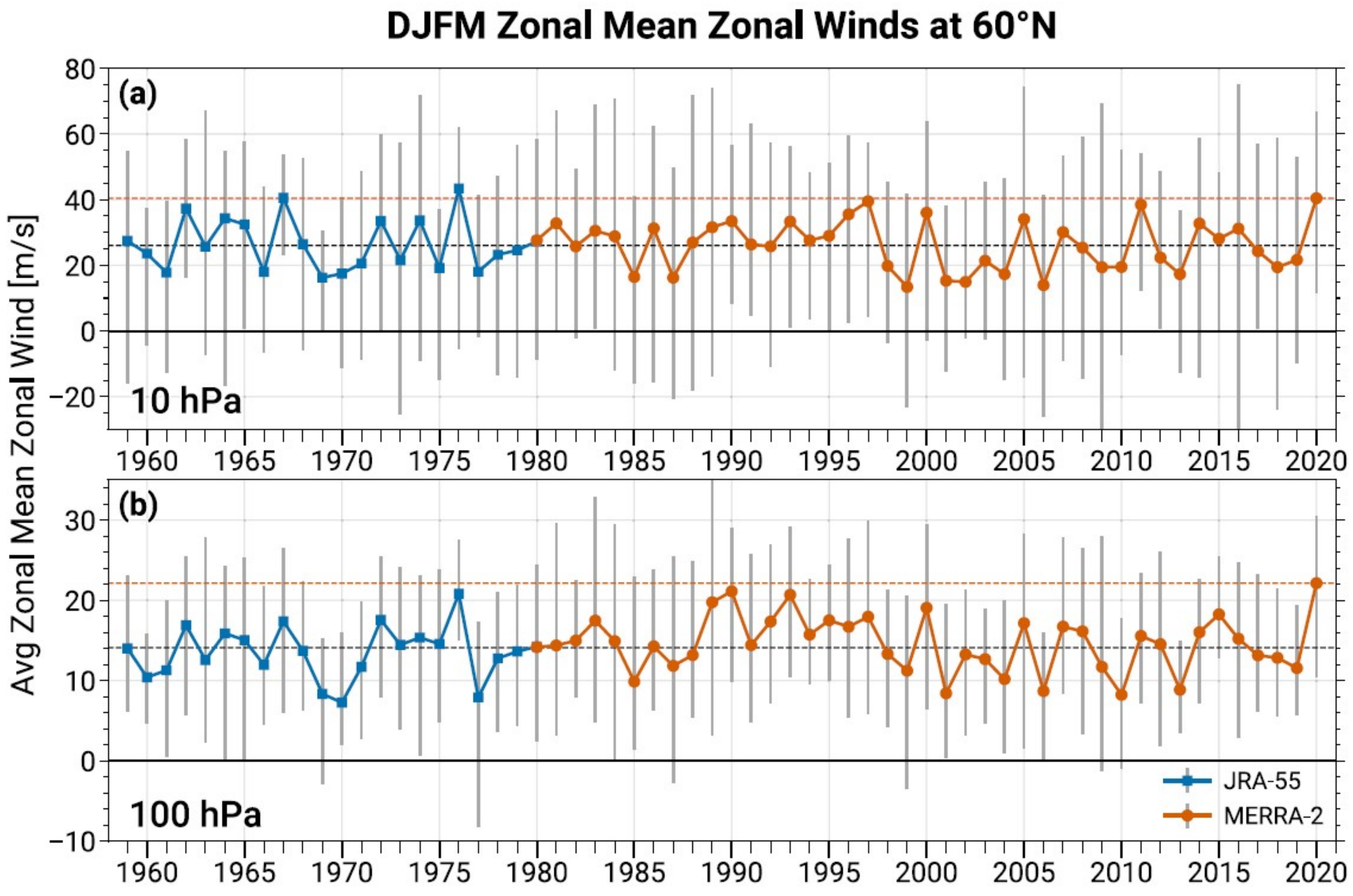
- <u>Strongly positive AO means stronger than usual pressure systems</u>

- Same AO over longer timescale means, pressure distribution is rather stationary

Data and Methods- MUAM

- **M**iddle and **U**pper **A**tmosphere **M**odel
- Based on the "Cologne Model of the Middle Atmosphere - Leipzig Institute for Meteorology" (in coorp. With RSHU in St. Petersburg)
- Nonlinear mechanistic 3D grid point model of neutral atmospheric circulation
- Geometric heights up to 240km
- In lower 30km, model is driven by reanalysis data of mean zonal temperature (NCEP- oder ERA-Interim reanalysis data)
- Includes „Nudging“ → model is adjusted to fit tropospheric model output (in lower levels)

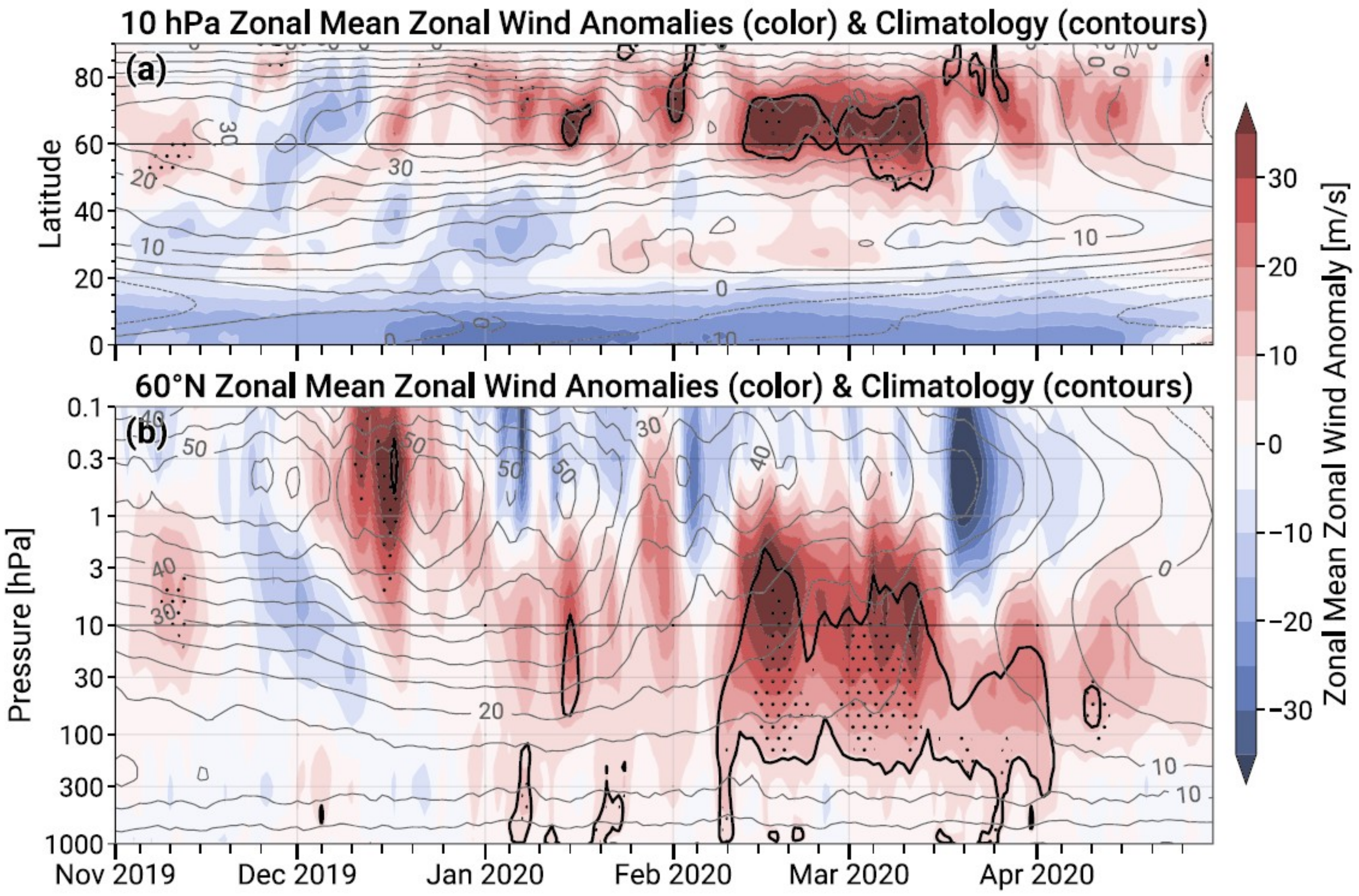
The 19/20 SPV – Strengh in context



- SPV 2020 strongest on record at 10 and 100 hPa for seasons back to 1979/1980
- Earlier, reanalysis is more uncertain because lack of sat-observations

Lawrence et al. (2020) https://doi.org/10.1029/2020JD033271

The 19/20 SPV – Strengh in context

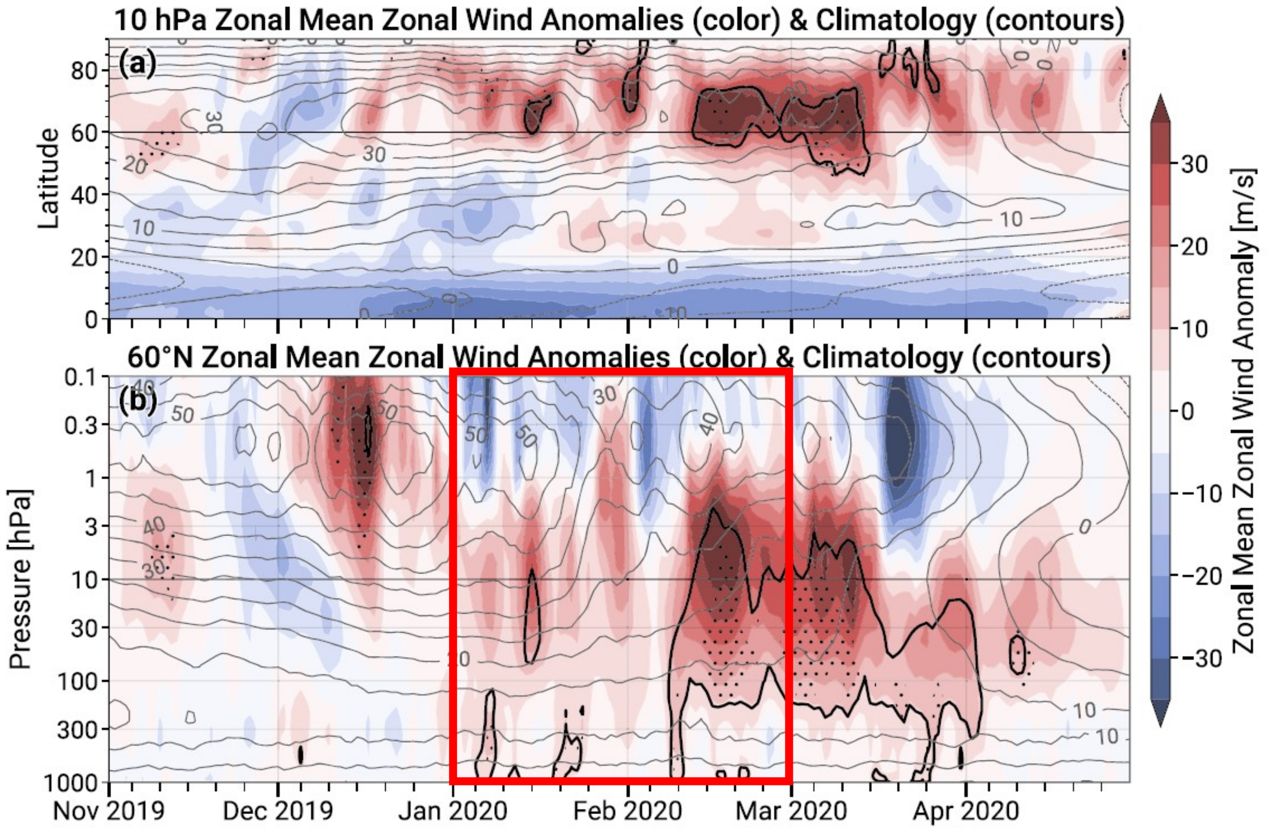


Lawrence et al. (2020) https://doi.org/10.1029/2020JD033271

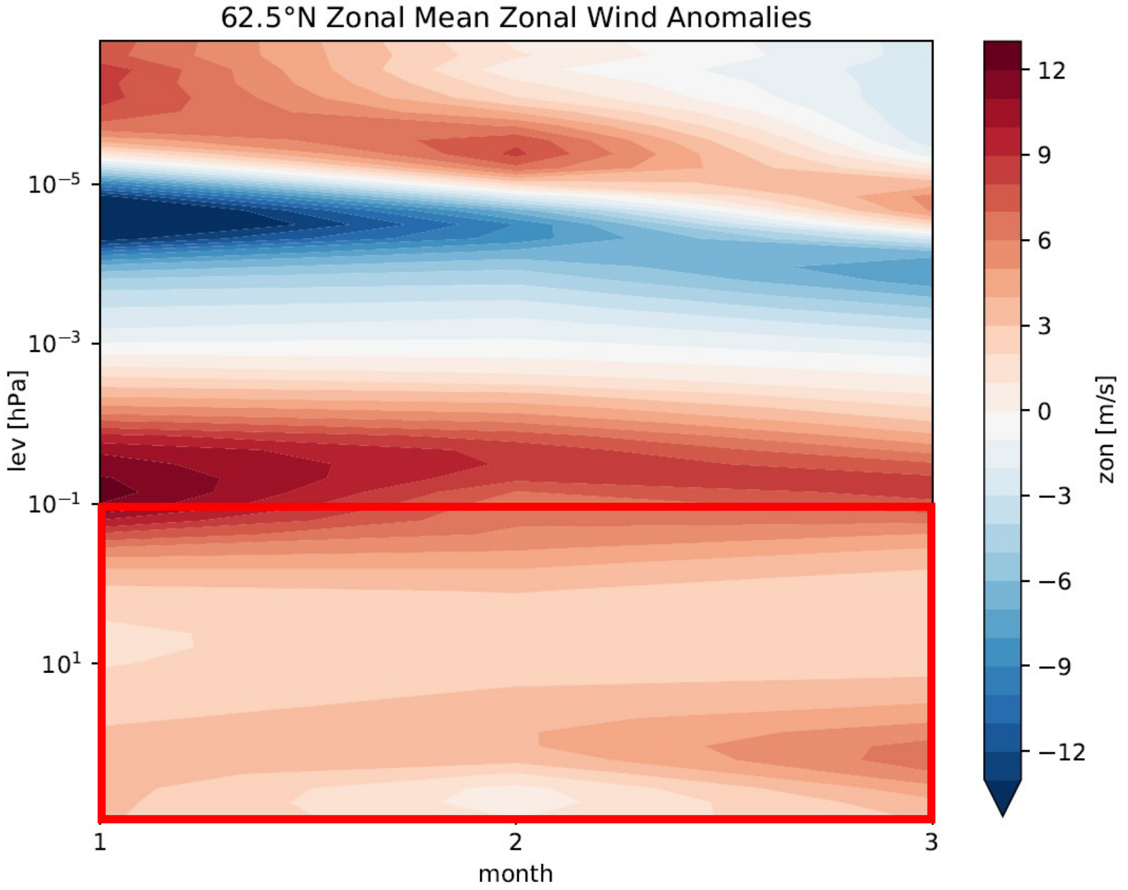
gray line contours represent the climatology

- SPV stronger than normal in the stratosphere between 100 and 1 hPa from November to April
- short-lived vortex disturbance from mid-November to early December
- black lines enclose the times when anomalies exceed +2 standard deviations
- Dotted region Merra 2 all time record

MERRA 2- Compared with MUAM

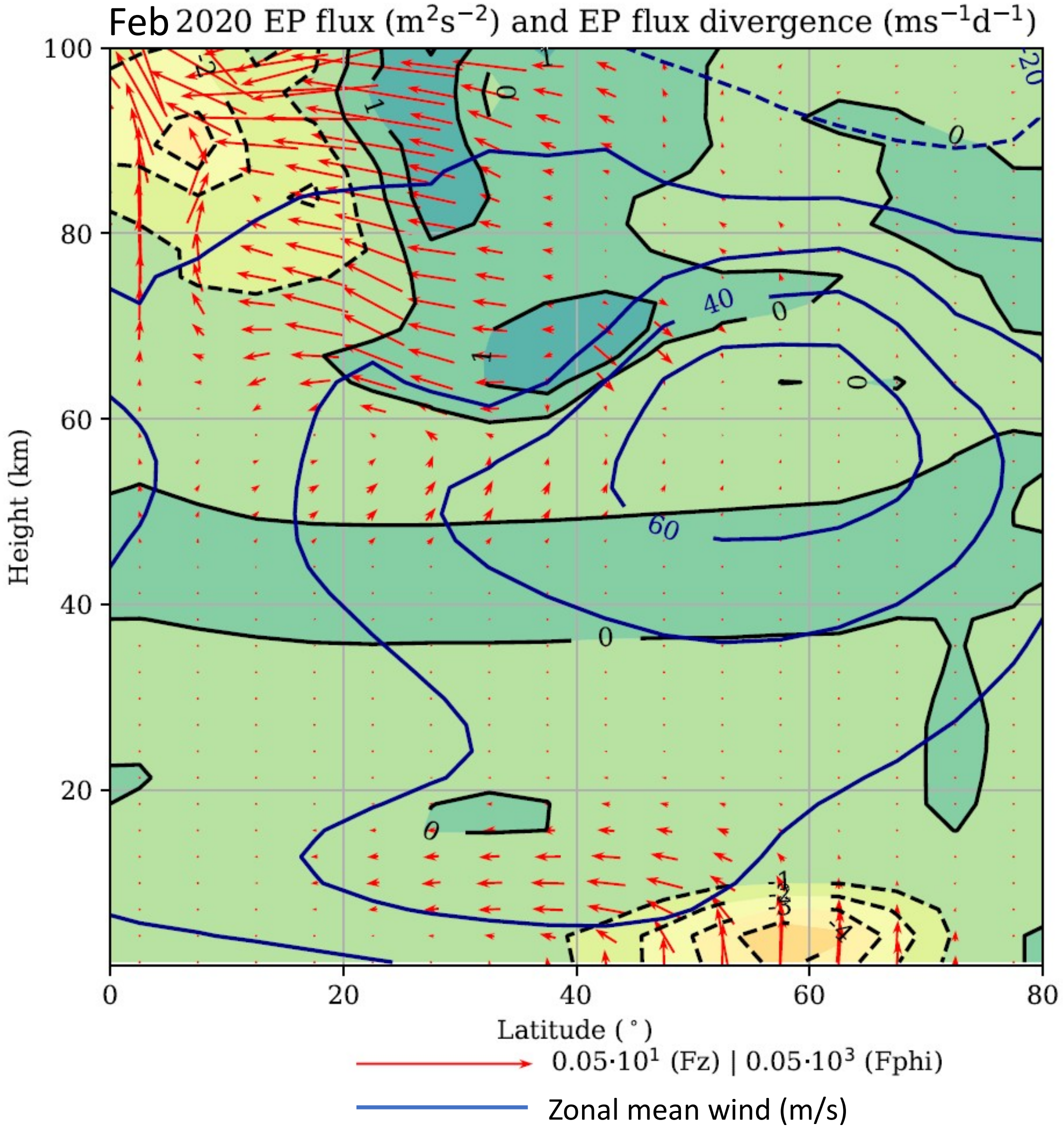


Lawrence et al. (2020)



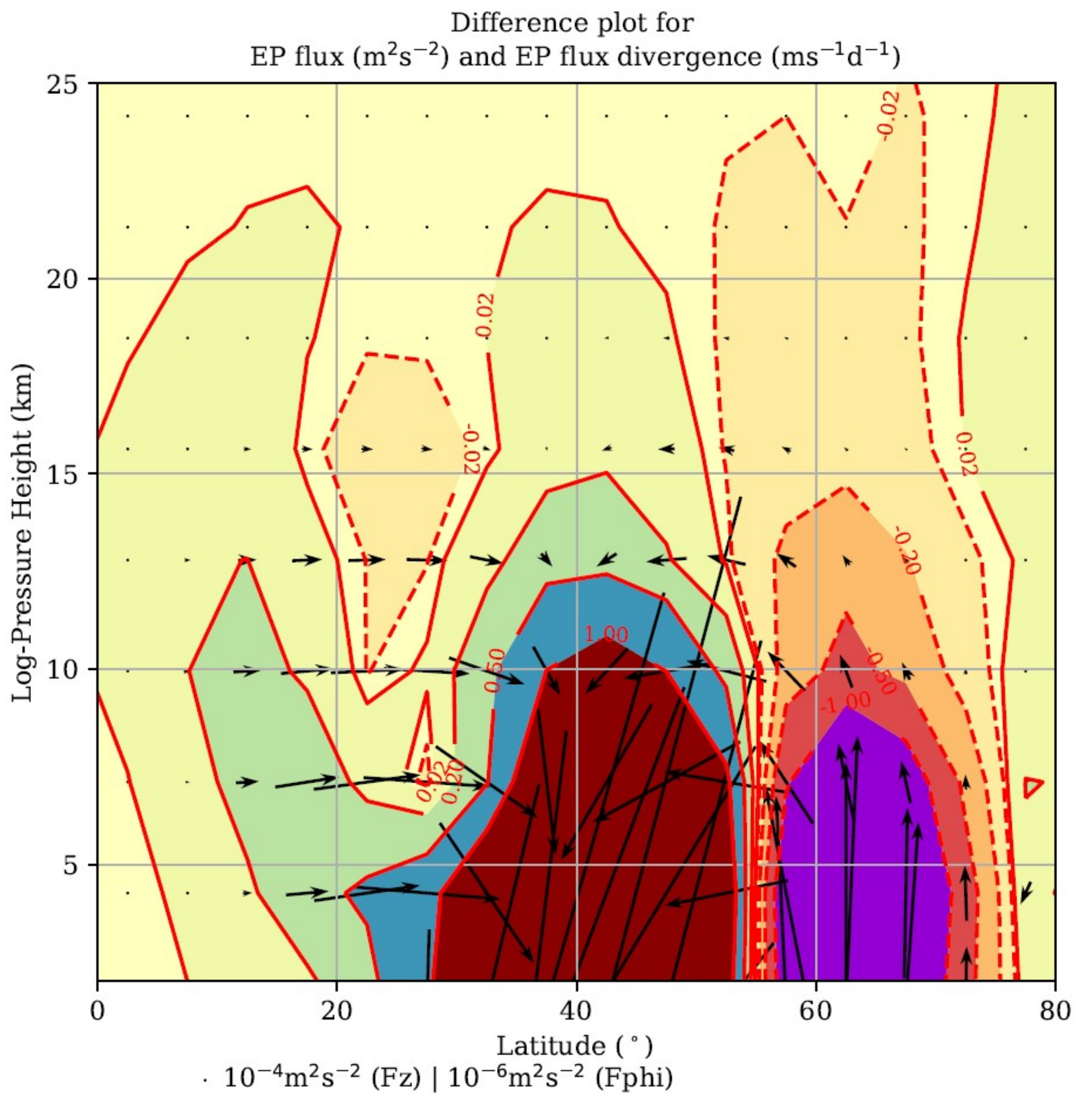
- The nicely definded maxima from the Merra2 data do not show in MUAM → only monthly means in MUAM
- Due to nudging, the positive anomalie in the troposphere jet is visible in MUAM
- MUAM anomalies regarding 2008 - 2018

The 19/20 SPV – EP flux and divergence



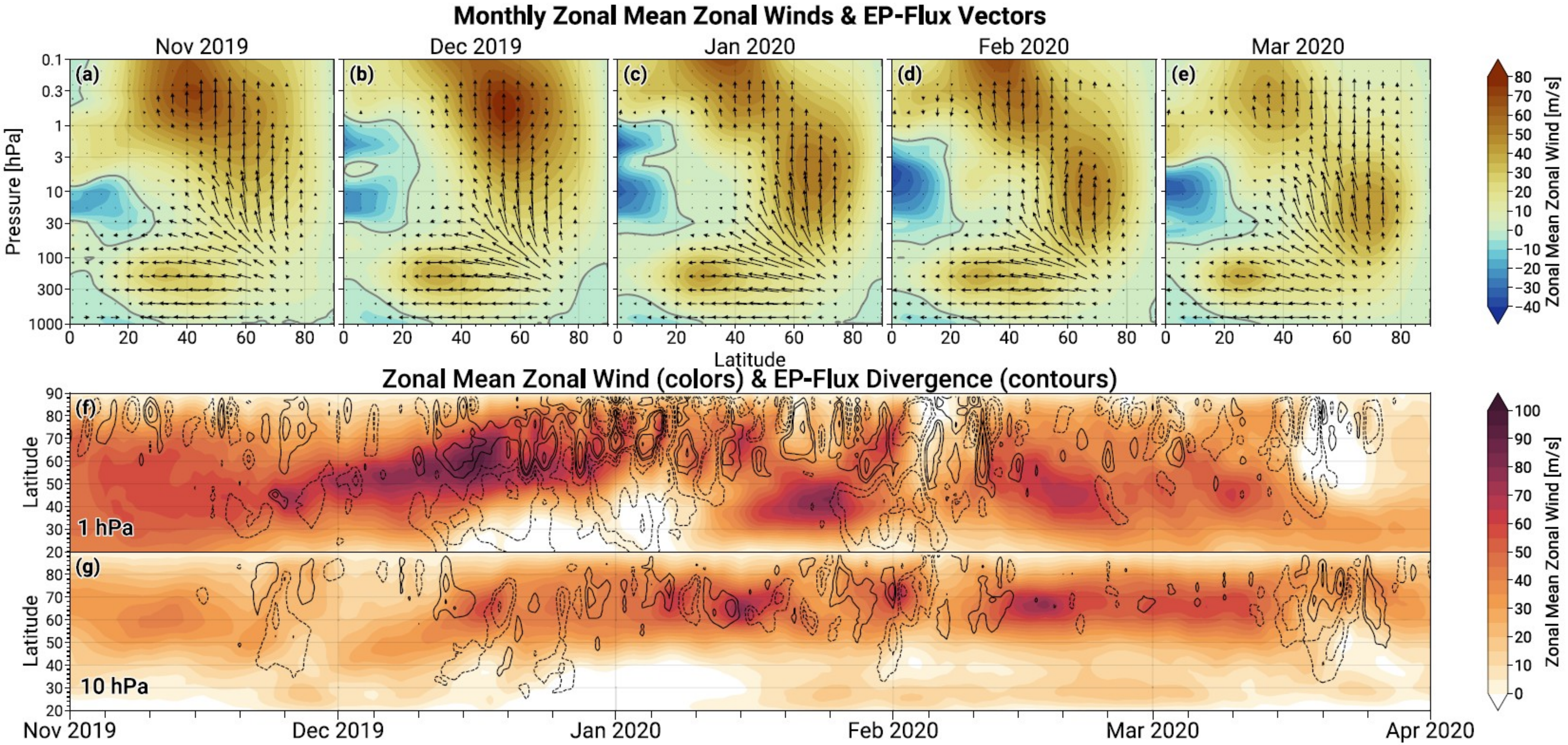
- <u>EP Flux and divergence + mean zonal wind in February</u>
- Strong SPV - hinders waves from traveling upwards → equatorward and upward travel is also hindered
- „split“ jet structure → high-latitude jet maximum (around 50–70◦N) in the lower to upper stratosphere and a low-latitude subtropical jet maximum
- shown to be highly reflective for stationary wave number 1 → zonal wind minima in low to middle-latitude lower and middle stratosphere meridionally confines waves (*Lawrence et al. 2020*)
- strong negative zonal wind shear acts as a vertical “cap” beyond which wave propagation is impaired
- <u>Also monthly mean!</u>

The 19/20 SPV – EP flux and divergence anomalies



- Difference from EP Flux and divergence between 2020 and 2008-2018 mean
- Strong SPV - hinders waves from traveling upwards → equatorward and upward travel is also hindered because of split jet
- Monthly means!

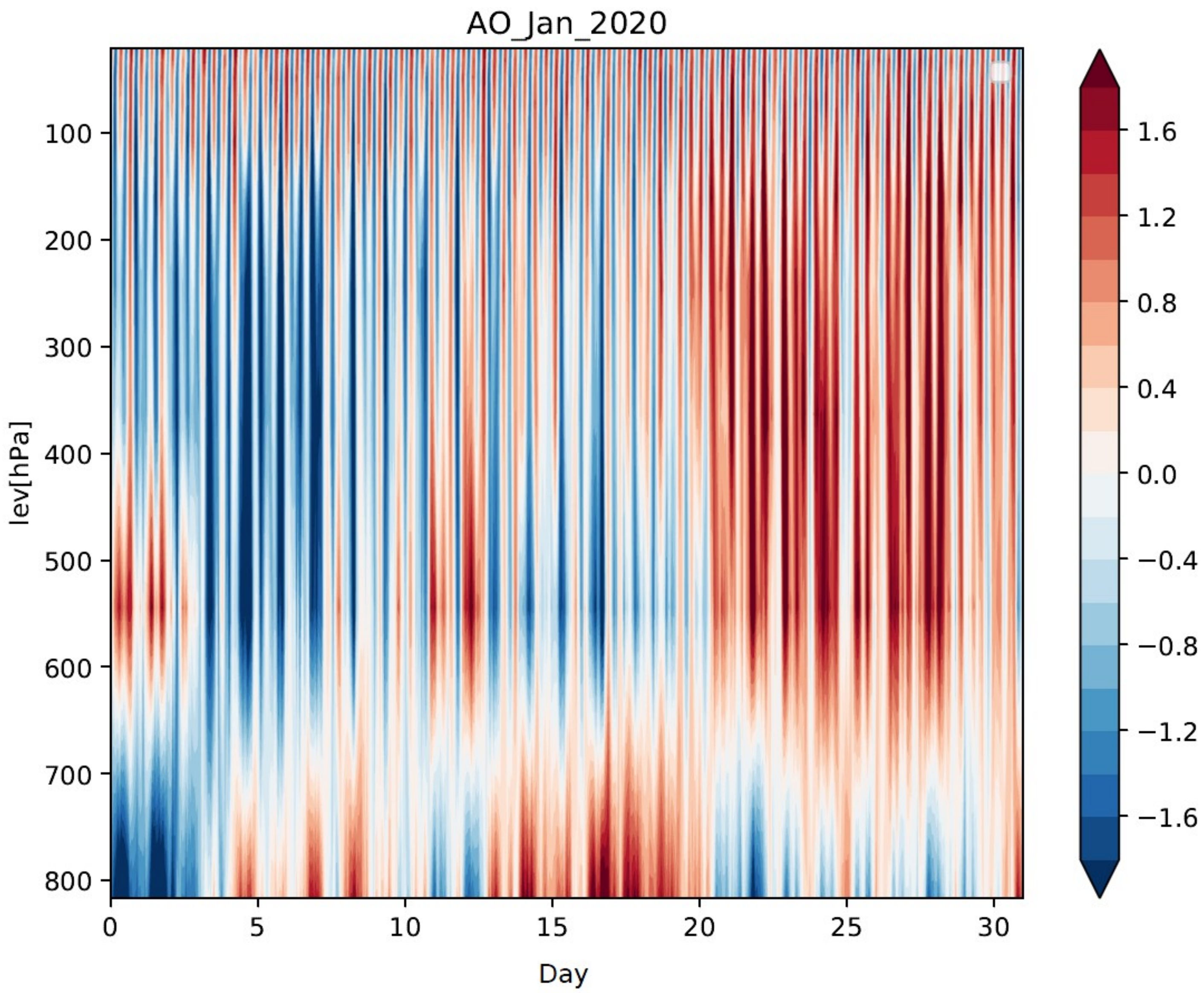
The 19/20 SPV – EP flux and divergence (MERRA 2)



Lines→ acceleration by EP flux divergence ±[8, 16, 32, 64] m/s/day
Colored contours → mean zonal wind

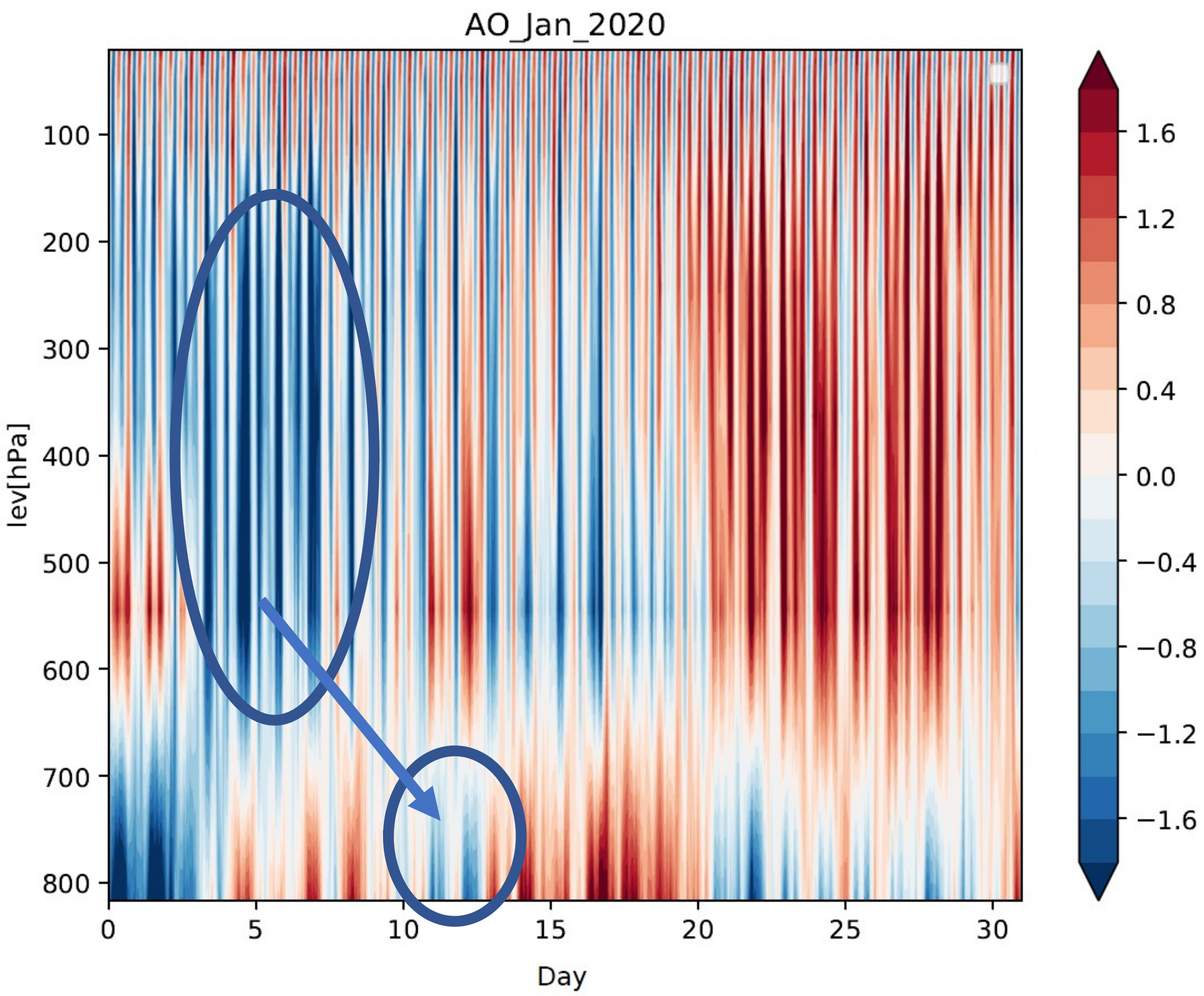
Lawrence et al. (2020)

The 19/20 SPV – Troposhere-Stratosphere coupling



- AO computed with aostools from MUAM data
- Diurnal Oscillations not right - MUAM data/postprocessing mistake

The 19/20 SPV – Troposhere-Stratosphere coupling



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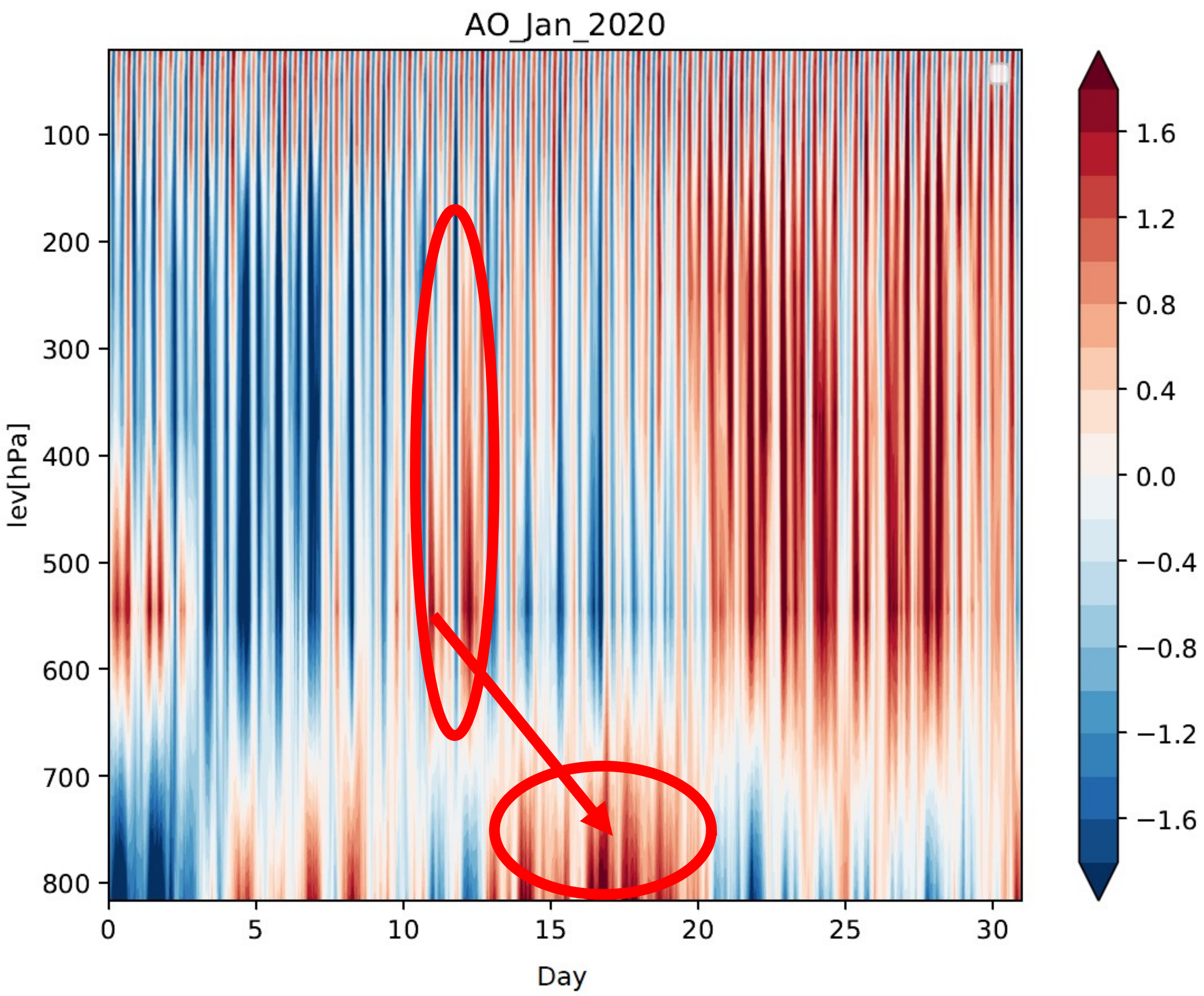

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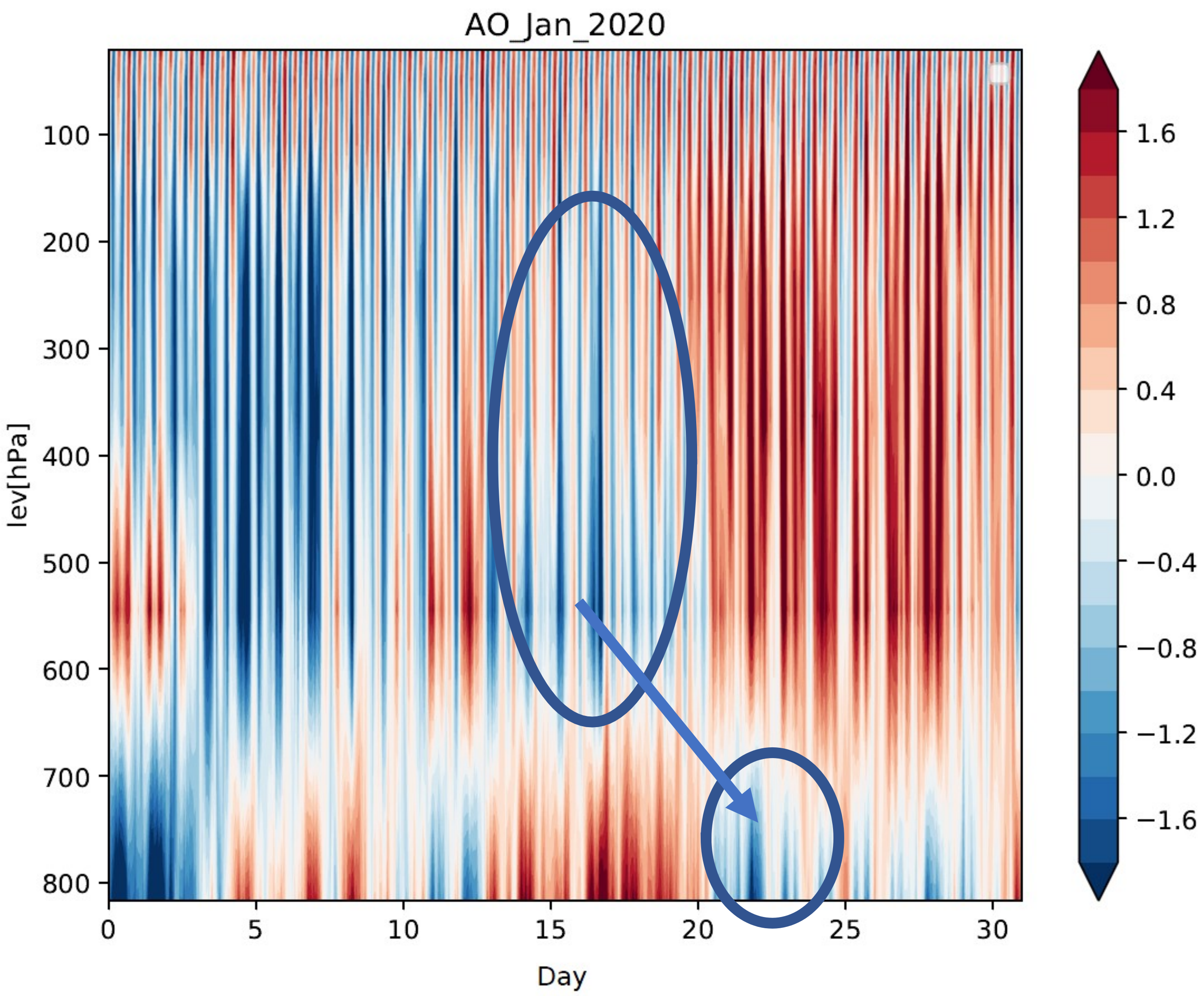
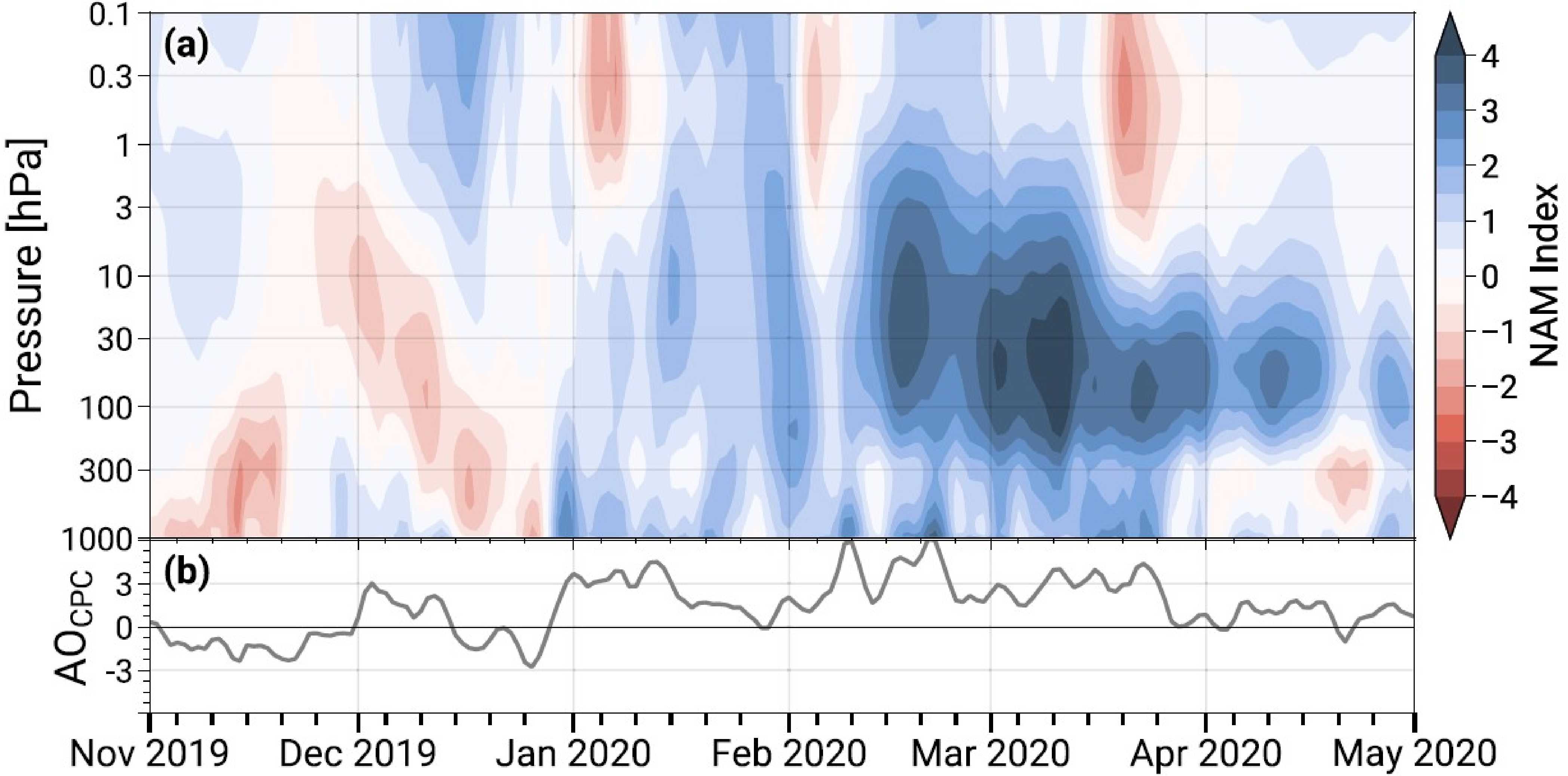


NAM and AO (MERRA 2)



Lawrence et al. (2020)

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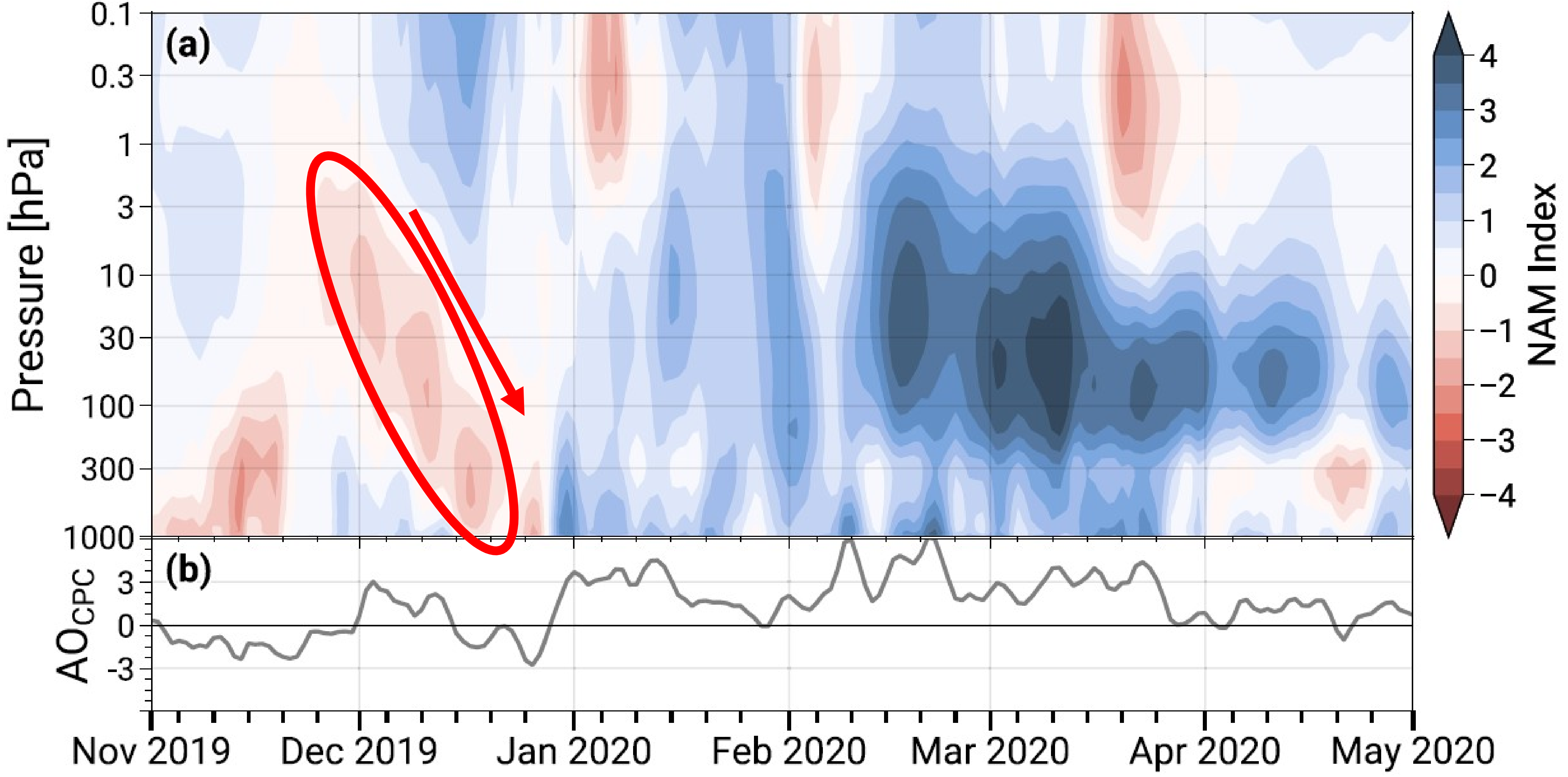

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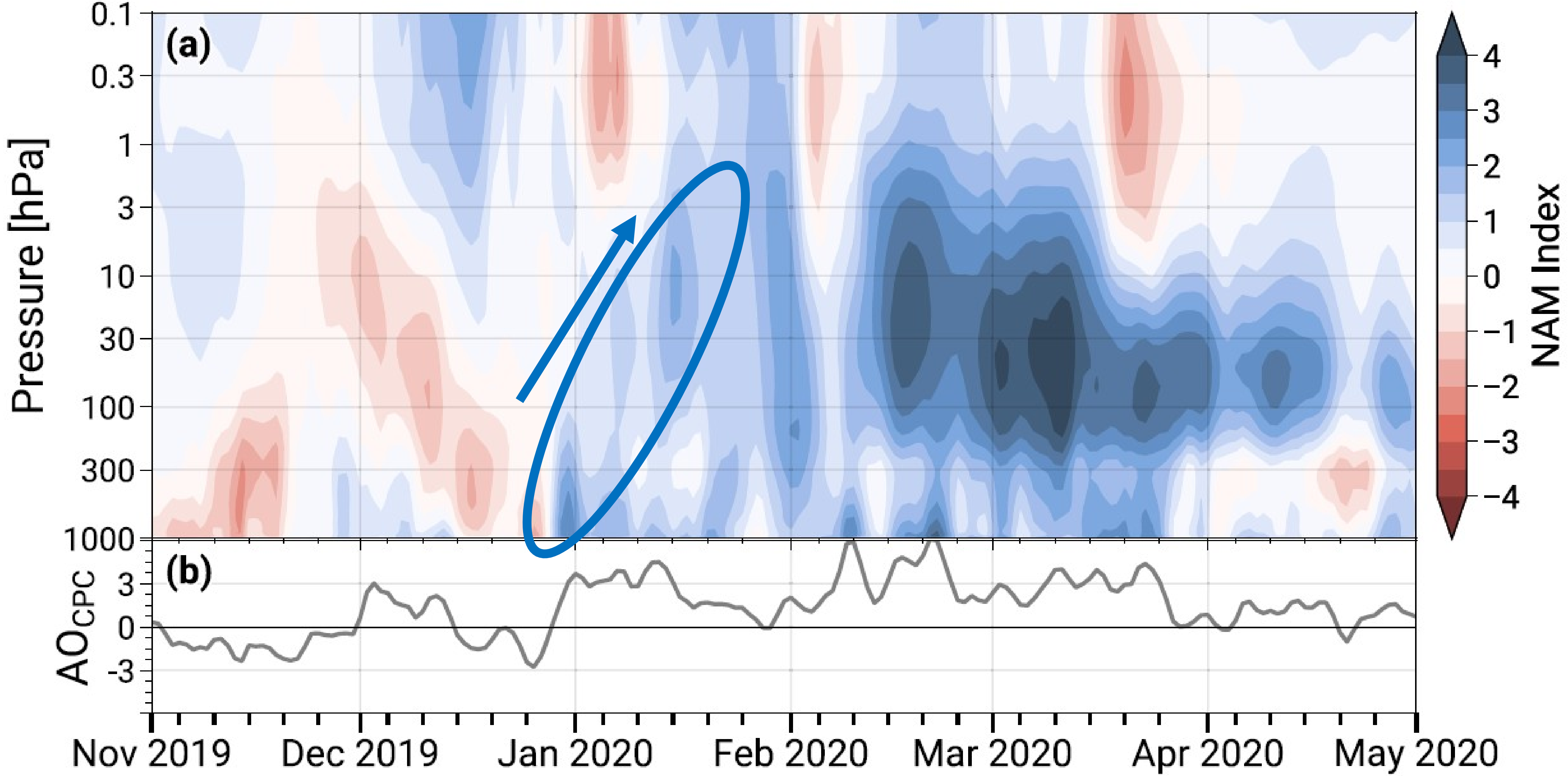

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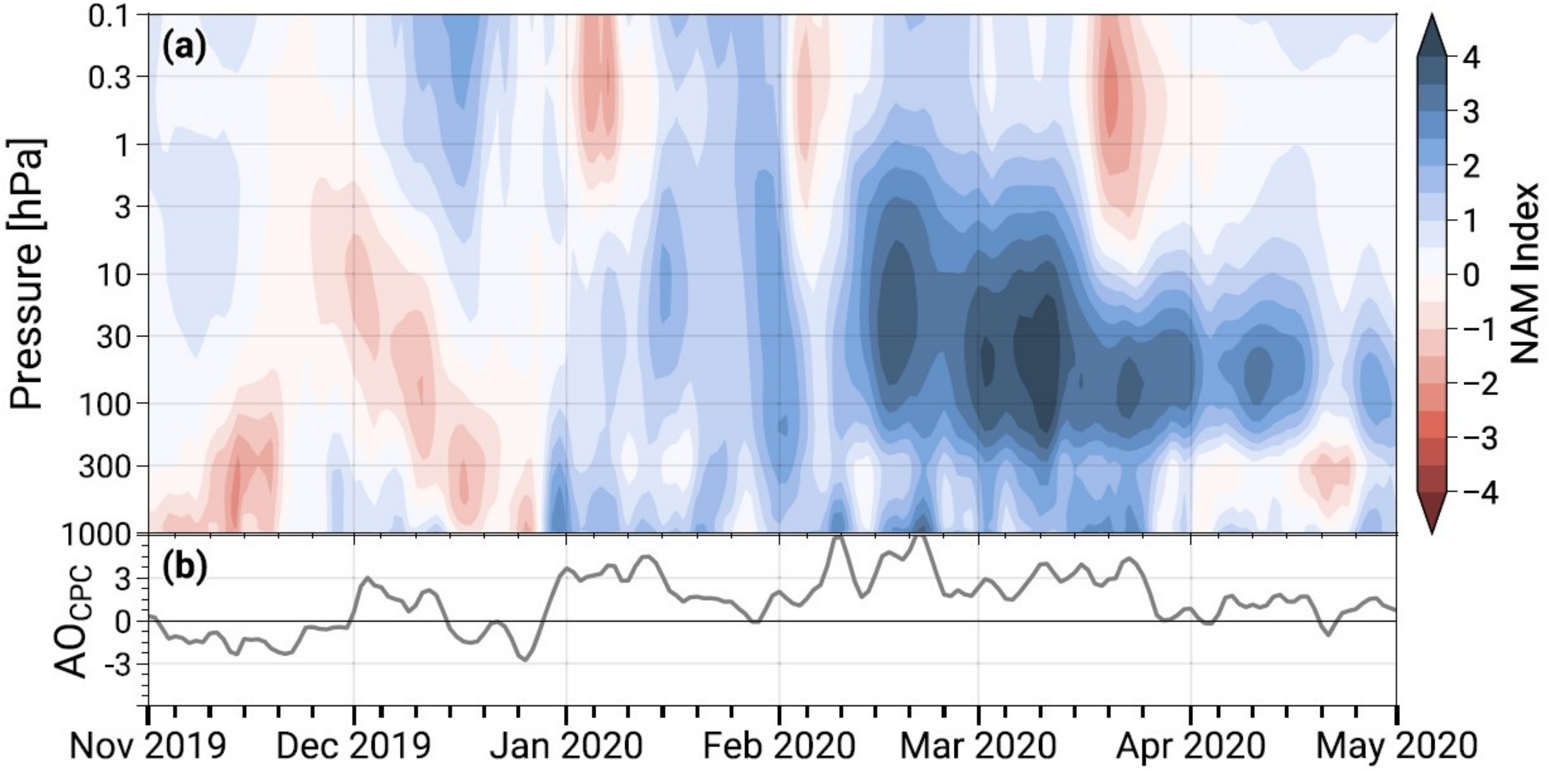
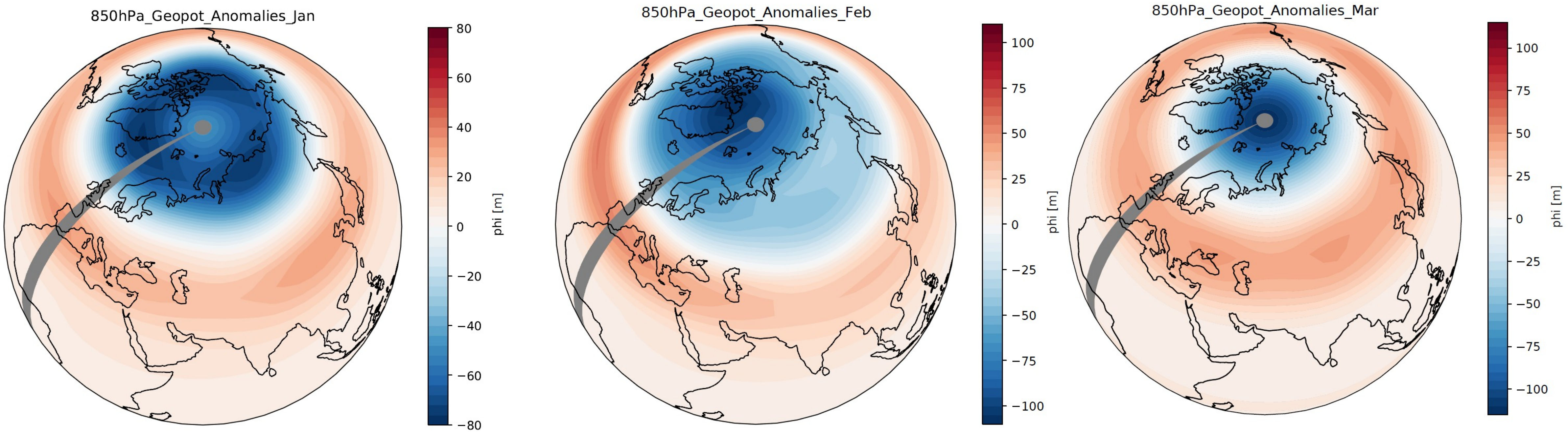


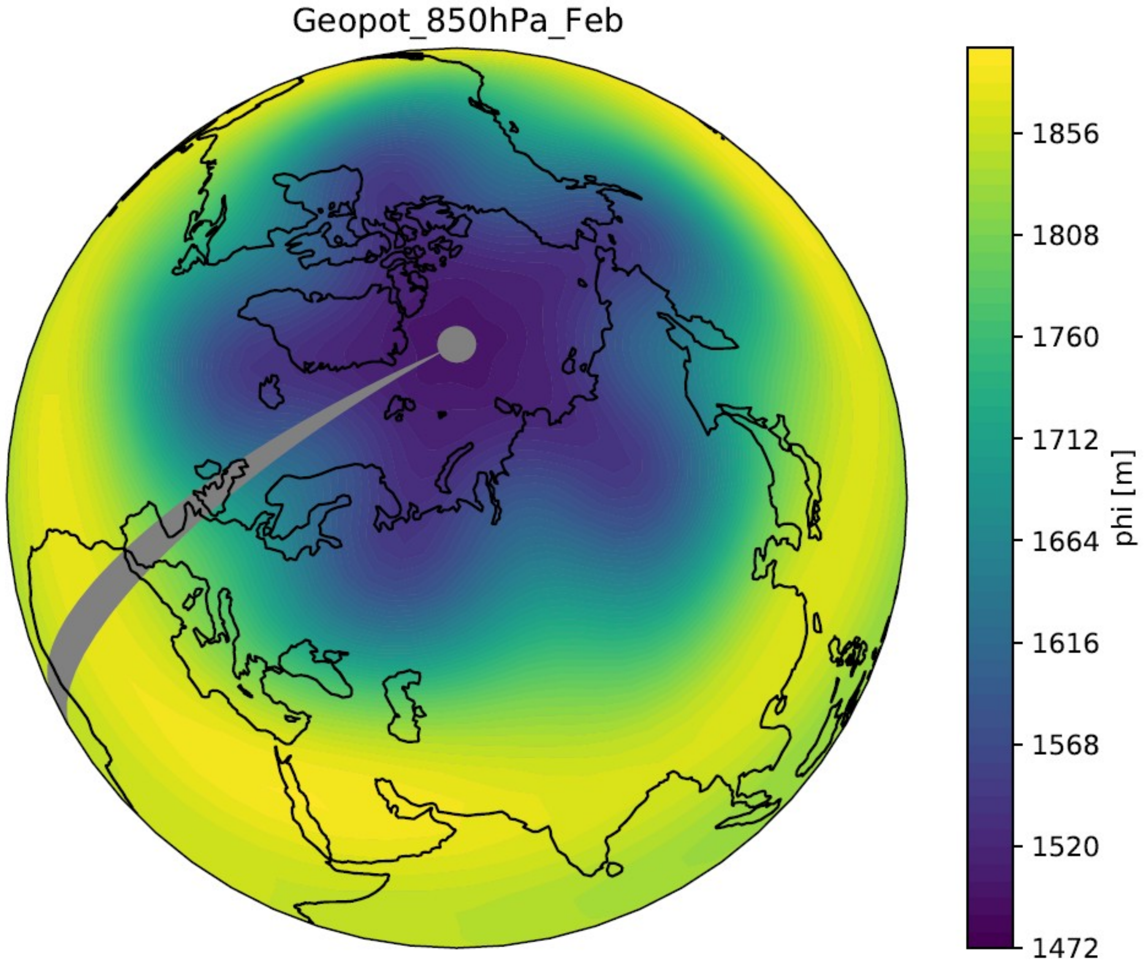
- Strong couling between troposphere and stratosphere NAM
- There is a significant correlation between 50hPa NAM and polar see level pressure (*Lawrence et al. 2020*)

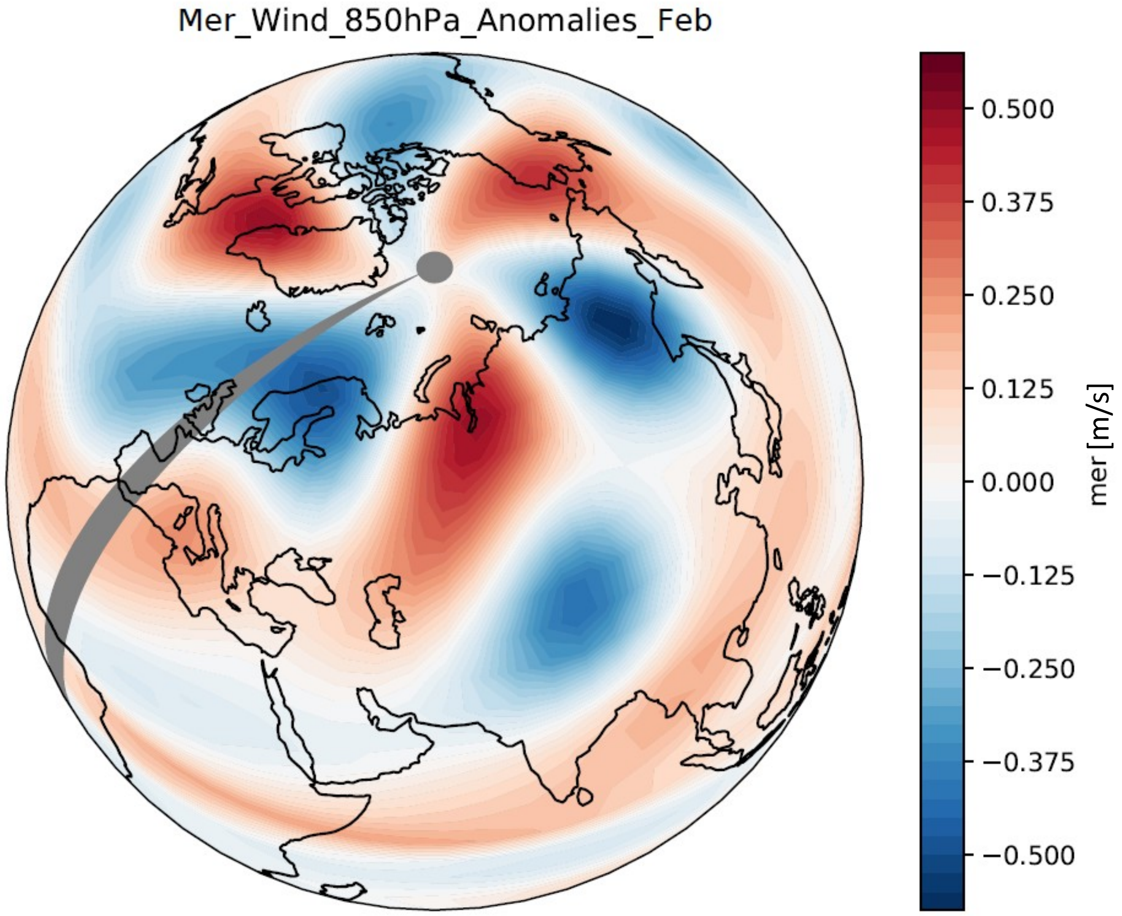
850 hPa Geopot. anomalies MUAM

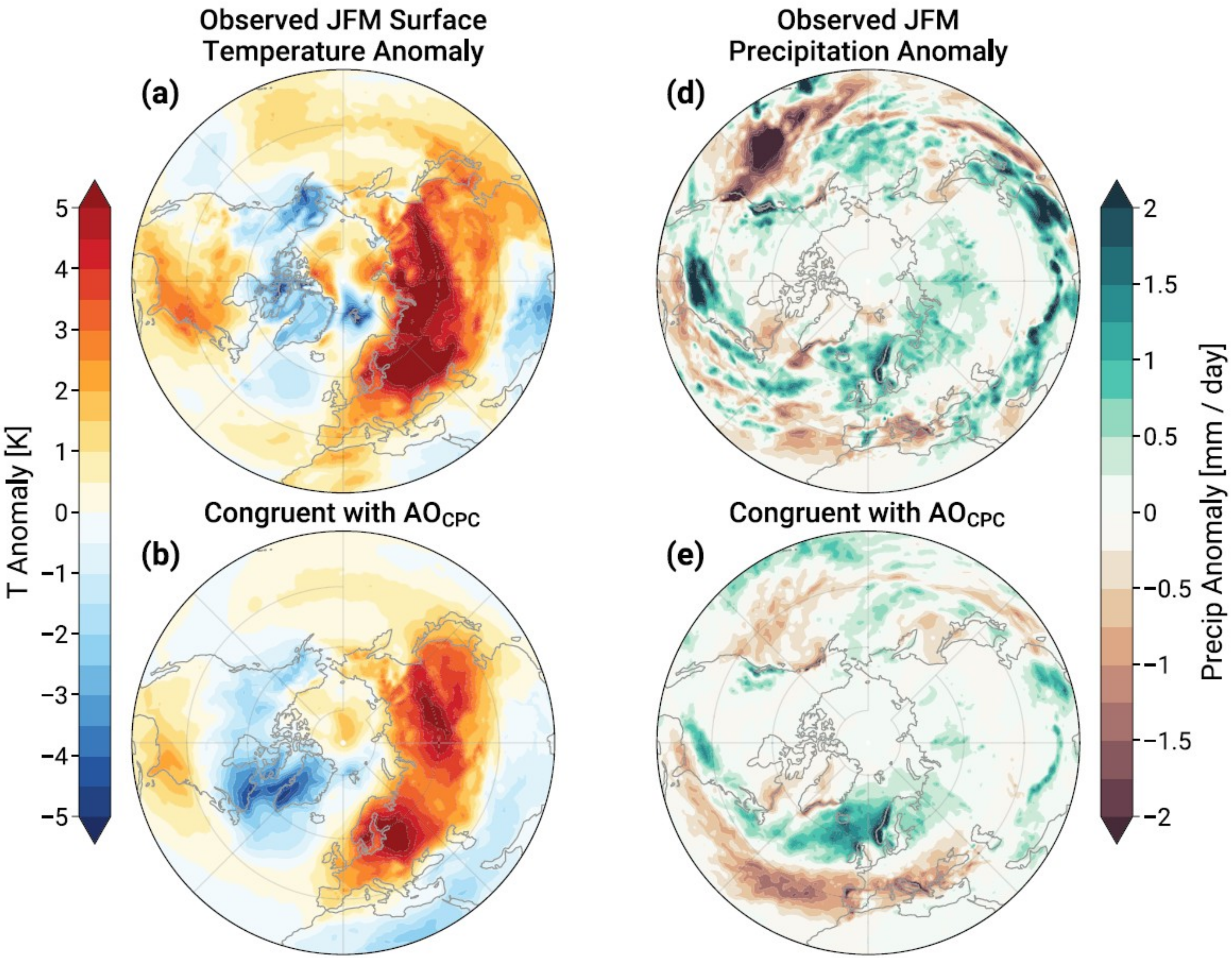


- pattern of anomalously low pressure in the polar cap, surrounded by a ring of anomalously high pressure in midlatitudes

850 hPa mer. wind. anomalies MUAM







MERRA 2

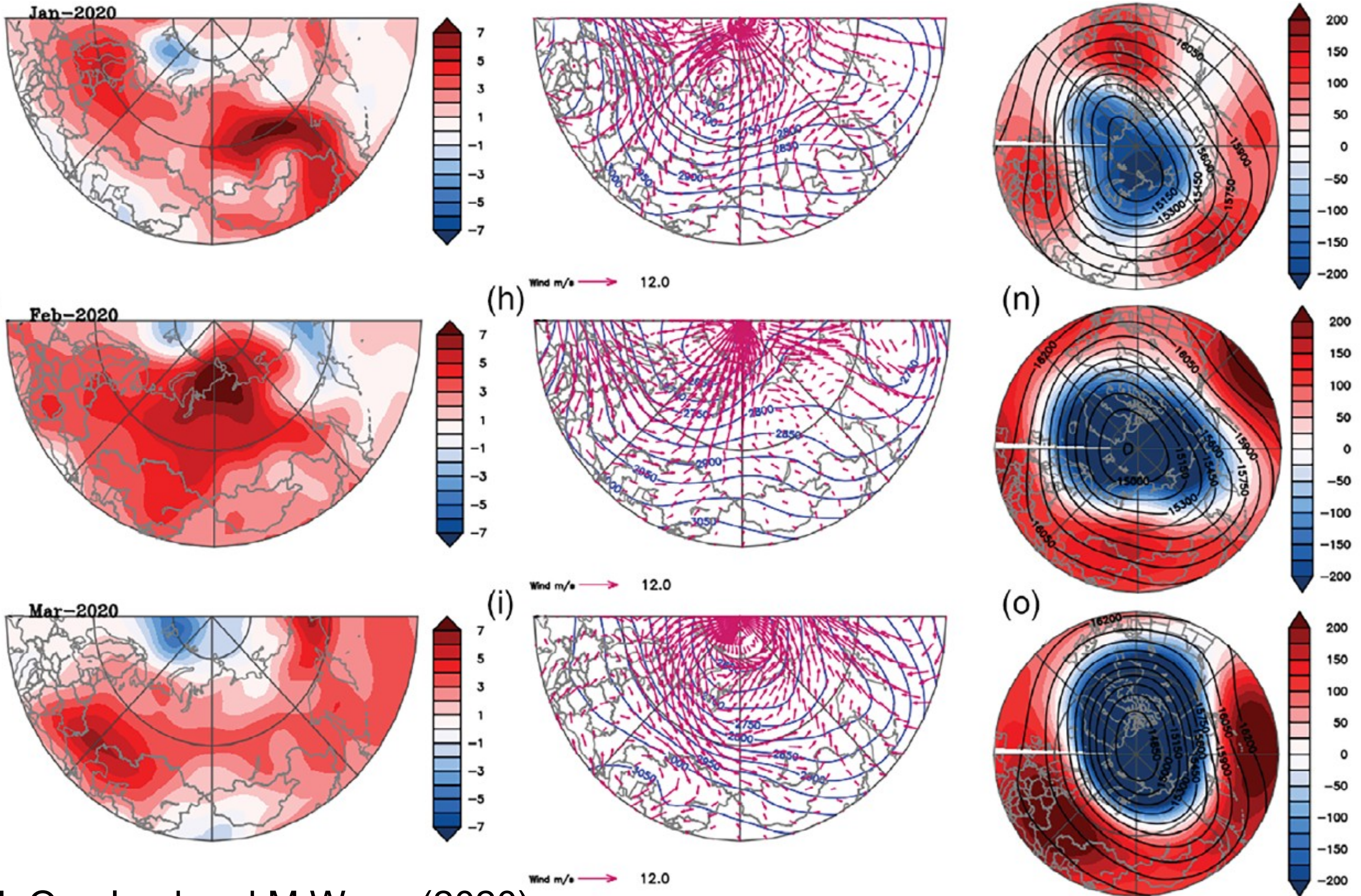
Lawrence et al. (2020)

Anomalies that would be expected due to the observed AO

<u>2/3 of anomalies explained by strongly positive AO</u>

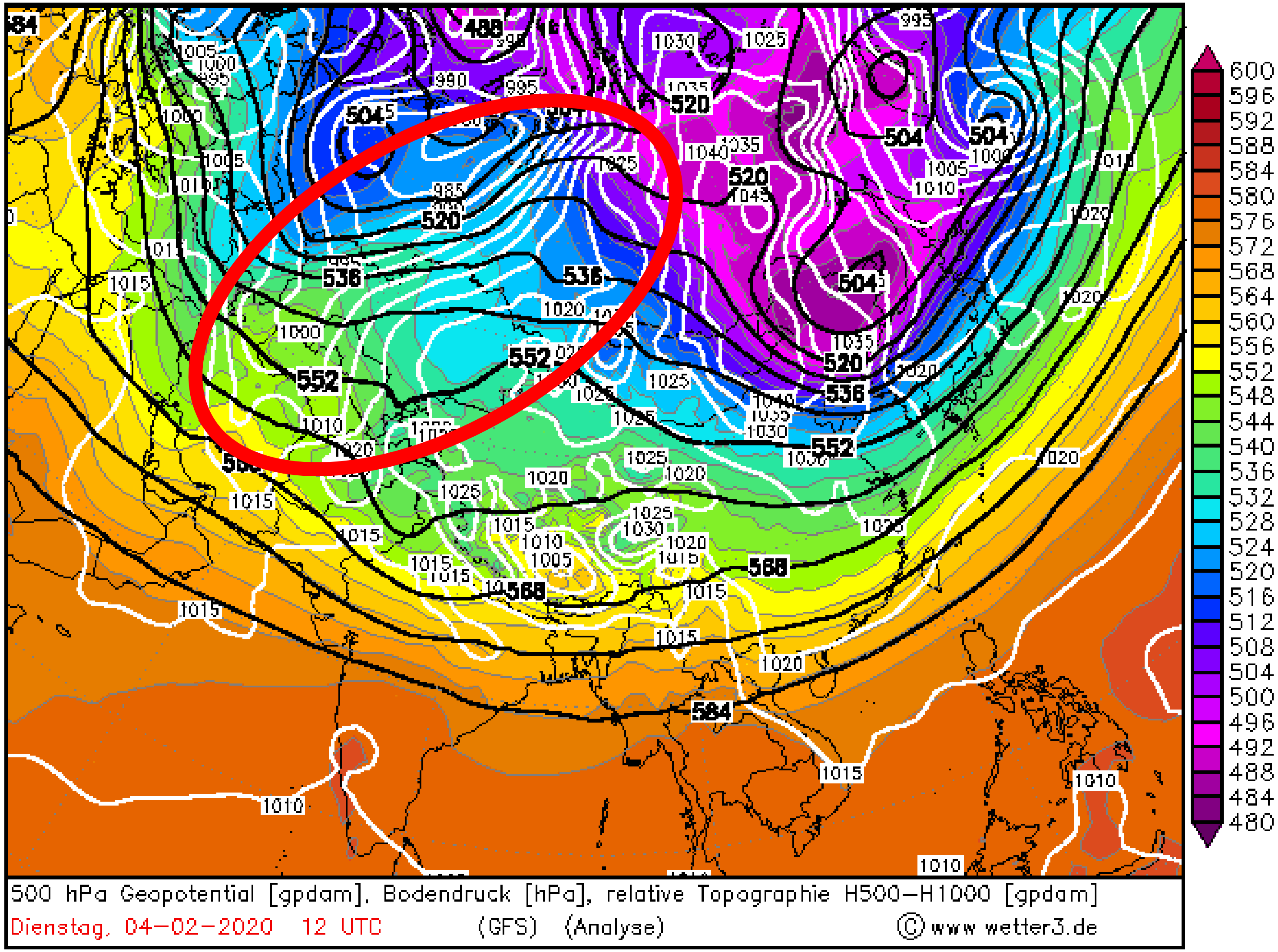
NCEP-NCAR Data reanalysis

925 hPa Temp. anom. [K] | 700 hPa Geopot + wind. anom. [m/s] | 100 hPa Geopot. anom. [m]

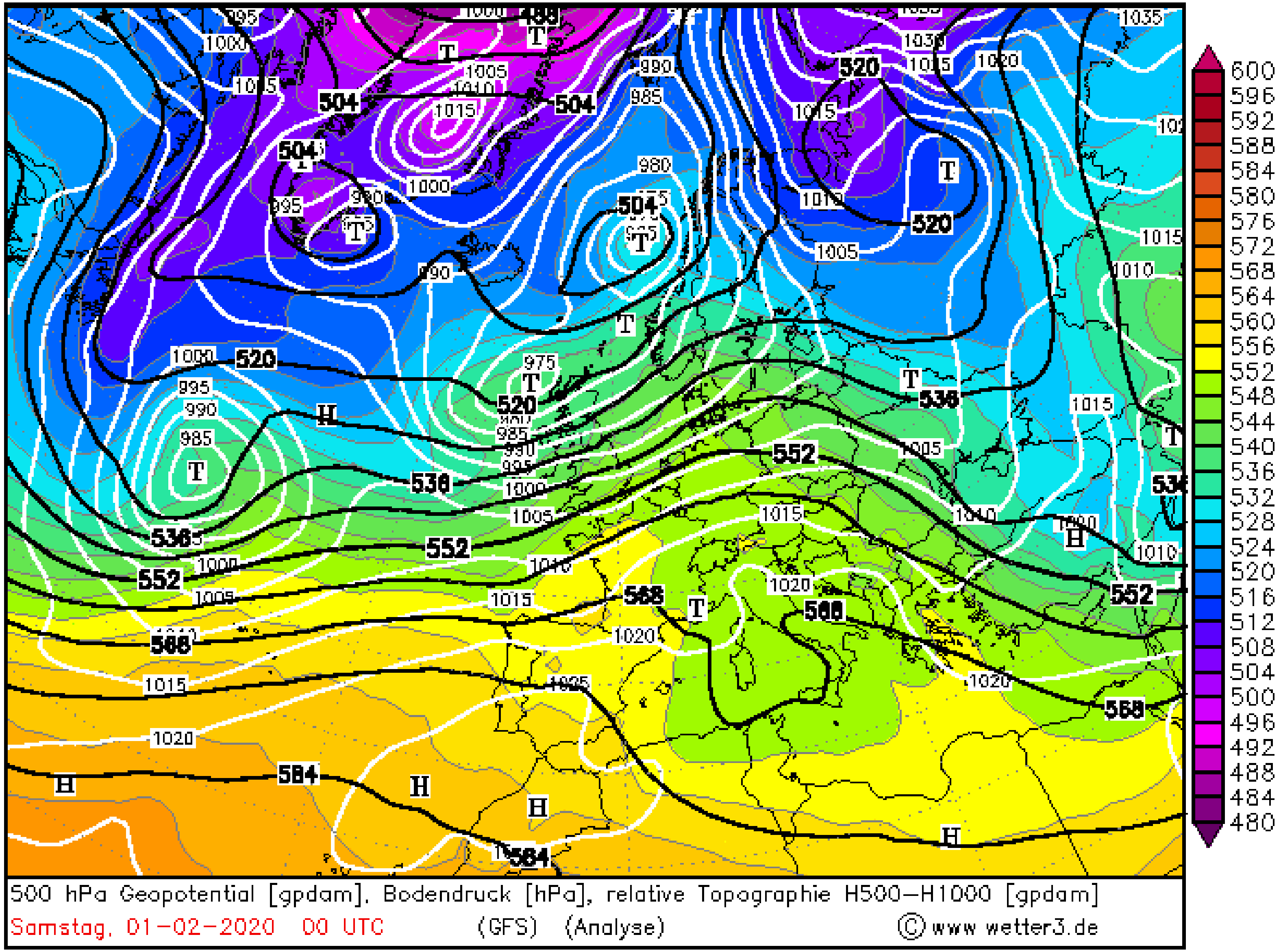


J. Overland and M.Wang (2020)

Northward advection of air masses



www.wetter3.de



- Very strong west wind drift due to highly positive AO

Summary

- SPV was exceptionally strong from Jan-Apr 2020

- Reasons where:

→weak tropospheric wave driving → no long-lasting SSWs

→reflective configuration of the polar vortex

→downward wave coupling events

- January–March 2020 mean AO was the most positive on record
- Large fractions of temperature and precipitation anomalies in JFM were consistent with AO
- direction of causality between the strongly positive NAM in the stratosphere and strongly positive AO in the troposphere remains somewhat unclear

- MUAM with monthly means is not perfect to show these transient effects

Main Sources

Lawrence et al., (2020). The remarkably strong Arctic stratospheric polar vortex of winter 2020: Links to record-breaking Arctic Oscillation and ozone loss. *Journal of Geophysical Research: Atmospheres*, *125*, e2020JD033271. https://doi.org/10.1029/2020JD033271

https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change

J. Overland and M.Wang., (2020). The 2020 Siberian heat wave. *International Journal Climatology*, DOI: 10.1002/joc.6850