Reply to Referee 1:

Referee comments on "Decadal Changes of Connections among Snow cover in West Siberia, Eurasia Teleconnection and O_3-related meteorology in North China" by Zhicong Yin et al.

This study makes a full investigation about connection between snow cover/EU teleconnection and O_3 pollution in north China. The April-May snow cover in West Siberia was proposed as a preceding climate driver that influenced the summer surface O_3-related meteorology in North China during 1980–1998, and the associated physical mechanisms were also explained by comparing the periods before and after the mid-1990s. The results of this study could provide a reference for the seasonal prediction of O_3. This paper is well written and organized. I recommend it to be published in ACP after several minor corrections.

1. Based on the content in the main text, the O_3-related meteorology (OWI) is focus on summertime. I would suggest to clarify the specific season in the title, which will give a more direct expression about the seasonal prediction mechanism.

Reply:

We have added the specific seasons in the title as suggested.

Revisions:

Title: Decadal Changes of Connections among **late-spring** Snow cover in West Siberia, **summer** Eurasia Teleconnection and O_3-related meteorology in North China.

2. The high level O_3 concentrations before mid-1990s are considered to be connected with the positive phase of EU teleconnection. While, after mid-1990s, the northward shift of snow cover results to the insignificant connections between snow anomalies, EU pattern and O_3. What is the possible reason for the change point of mid-1990s? That is, why 1990s was selected as the turning point in this study. Is it based on the statistical analysis or some physical mechanisms?

Reply:

(1) As shown in Figure 3c, we calculated the 21-year sliding correlation coefficient between SC_{WS} and OWI. The results showed that the correlation coefficient was **significant before the mid-1990s and insignificant after the mid-1990s between SC_{WS} and OWI**. Therefore, according to the significance of the correlation coefficient, we directly divided the study period into two equilong periods.

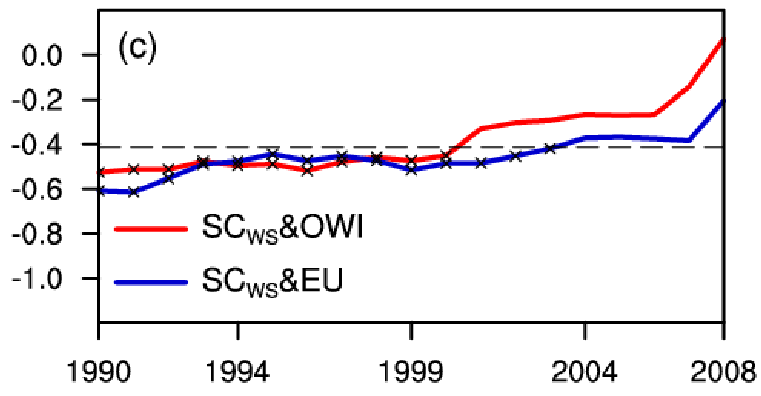

Figure 3c. The 21-year sliding correlation coefficients between SC_{WS} and OWI (red), EU (blue). The black dotted line (crosses) indicates (exceeded) the 95% confidence level. The linear trend is removed.

(2) In addition to mathematical statistics, the physical mechanisms were also explained. The main point is, **compared to P1**, **the south edge** of the area with high concentrations **of snow** (>85%) in late spring **shifted northward** by approximately 2° in latitude **during P2** (Figure 4a).

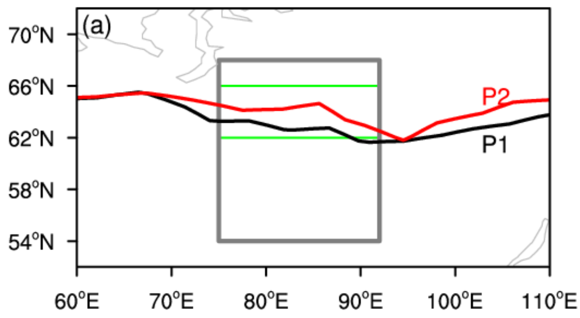

Figure 4a. The south edge of the 85% snow cover concontration during 1980–1993 (black) and during 2004–2018 (red). The gray (green) box represents the key area used to calculate the NHF_{WS} (SCsw) index.

(3) Actually, many previous studies have pointed out mid-1990s was a turning point of correlation relationships, such as Yin and Wang (2018), Wu et al., (2009) and Zhang et al., (2020). In our study, we also only tracked the signal to the south edge of April-May snow cover. Indeed, the reasons why the turning points generally occurred in mid-1990s were still unclear, but needed further researches.

Related References:

Yin, Z. C., and Wang, H. J.: The strengthening relationship between Eurasian snow cover and December haze days in central North China after the mid-1990s, Atmos. Chem. Phys., 18, 4753–4763, https://doi.org/10.5194/acp-18-4753-2018, 2018.

Wu, B. Y., Yang, K., and Zhang, R. H.: Eurasian snow cover variability and its association with summer rainfall in China, Adv. Atmos. Sci., 26, 31–44, https://doi.org/10.1007/s00376-009-0031-2, 2009.

Zhang, R. N., Sun, C. H., Zhu, J. S., Zhang, R. H., and Li, W. J.: Increased European heat waves in recent decades in response to shrinking Arctic sea ice and Eurasian snow cover, npj. Clim. Atmos. Sci., 3, 7, https://doi.org/10.1038/s41612-020-0110-8, 2020.

3. Some detailed information about the calculation of OWI index in Line 105 are suggested to add. E.g., how to normalize the meteorological variables. The absolute value of observed O_3 concentration and OWI should be included to indicate the robust of OWI.

Reply:

Because the magnitude of each sub-index in OWI varied greatly, which would influence the effect of OWI, we need to normalize the meteorological variables to eliminate the impact of dimensions. **The normalized process is to divide the anomaly by the standard deviation.** And the robust relationship between OWI and observed MDA8 has been verified by Yin et al. (2019). The variations in the daily observational MDA8 and OWI from 2007 to 2017 are showed in Figure R1. **The correlation coefficient between the observed MDA8 and daily OWI was 0.61 for the period 2007-2017.** It meant that the change of OWI agreed well with that of ozone concentrations.

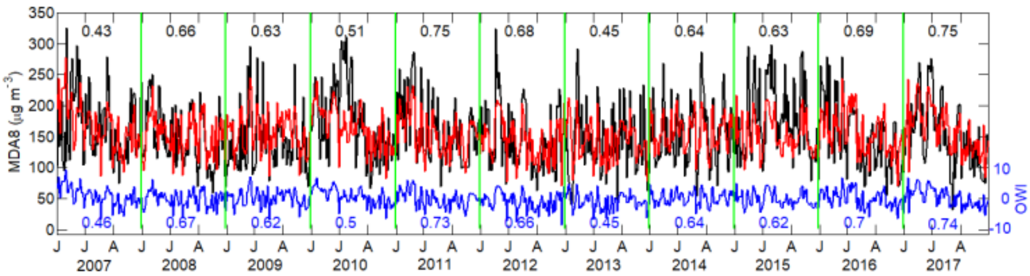

Figure R1. The variation in the daily observational SDZ MDA8 (black), fitting SDZ MDA8 (red), and OWI (blue) from June to August during 2007–2017. The numbers are the correlation coefficients between the observational SDZ MDA8 and fitting SDZ MDA8 (red) and OWI (blue).

Related References:

Yin, Z. C., Wang, H. J., Li, Y. Y., Ma, X. H., and Zhang, X. Y.: Links of climate variability among Arctic Sea ice, Eurasia teleconnection pattern and summer surface ozone pollution in North China, Atmos. Chem. Phys., 19, 3857–3871, https://doi.org/10.5194/acp-19-3857-2019, 2019.

Revisions:

Lines 103-107: In this study, we employed the ozone weather index (OWI) during 1980–2018, which has been defined by Yin et al. (2019; 2020b) and was proven to be a comprehensive and effective index determining the maximum daily average 8-h concentration of ozone (MDA8 O_3). **The correlation coefficient between the observed MDA8 and daily OWI was 0.61 for the period 2007-2017 (Yin et al., 2019).** The formula for OWI in North China is as follows:……

Lines 111-113: ….and the DTI is the area-averaged difference between the temperature at the surface (37.5°–47.5°N, 110°–122.5°E) and at 200 hPa (37.5°–50°N, 110°–127.5°E). **The normalized process is to divide the anomaly by the standard deviation.** These meteorological factors were selected based on ……

Reply to Referee 2:

Referee comment on "Decadal Changes of Connections among Snow cover in West Siberia, Eurasia Teleconnection and O_3-related meteorology in North China" by Zhicong Yin et al.

Yin et al. examined the possible impacts of snow cover over west Siberia on Eurasia teleconnection and ozone pollution meteorology in North China at the decadal timescale. They found that 1980-1998 changes in snow cover over west Siberia could modulate ozone pollution weathers over the North China through affecting the Eurasia teleconnection, but after that this connection tends to be insignificant. They also demonstrated that snow cover as well as sea ice could be the effective predictors for ozone pollution meteorology over the North China.Overall, this is a timely study with interesting results. It fits well within the scope of ACP journal. I hope it can be published in the near future while the following concerns should be addressed.

1. Fig3a: There is no doubt that snow cover over west Siberia is linked with ozone pollution in North China. However, I am wondering if OWI and SC_{WS} are still significantly correlated over 1980-1998 if the authors remove the 1997/1998 El nino years, which could have driven these evident interannual anomalies at a large scale. Similar question also for correlation between NHF_{WS} and EU/OWI in Fig.6a.

Reply:

(1) As the reviewer suggested, considering the possible effect of El Niño, we first removed the ENSO signal by subtracting the linear regression value of Nino3.4 index. Then, we re-calculated the correlation coefficient between OWI and SC_{WS} over 1980-1998, and its value was still -0.68 (above the 99% confidence level). Similarly, the correlation coefficient between NHF_{WS} and EU/OWI was 0.49/0.53 (above the 95% confidence level). **There was almost no difference between the correlation coefficients and that before the ENSO signal was removed.**

(2) In addition, we calculated the 21-year sliding correlation coefficient between Nino3.4 index and OWI (Figure R1). The correlation coefficients couldn’t pass the significance test, that’s to say, El Niño had little impacts on ozone in North China.

Revision:

Lines 207-210: ……between OWI and SC_{WS} was significant (−0.68, above the 99% confidence level) during P1 and became insignificant (0.20) during P2 (Figure 3c). Oppositely, the correlation with SI_{GR} enhanced from 0.4 in P1 to 0.62 in P2 (Figure 3d). **After removing the signal of El Niño-Southern Oscillation (ENSO), these correlation coefficients almost unchanged.**

Lines 263-265: The AM-mean NHF_{WS} showed significantly positive correlations with both the summer-mean EU (0.49) and OWI (0.52) during P1 (Figure 6a, S8a). **After removing the ENSO signal, these correlated relationships almost showed no difference**….

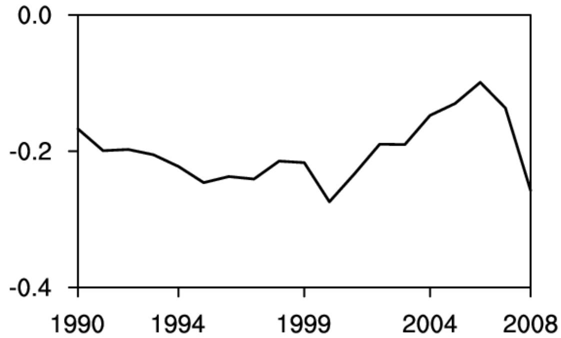

Figure R1. The 21-year sliding correlation coefficients between Nino3.4 index and OWI.

2. L97: Is Yin et al. (2020a) the first one to devise the EU index? If not, the original reference should be added.

Reply:

The calculation procedure for the EU index was based on the study of Wang and He (2015). However, according to correlation coefficients between the May sea ice index and JJA mean geopotential height at 500 hPa from 1979 to 2017 (Figure R2), the EU pattern's location had been fine-tuned. Then, the original reference has been added to the text.

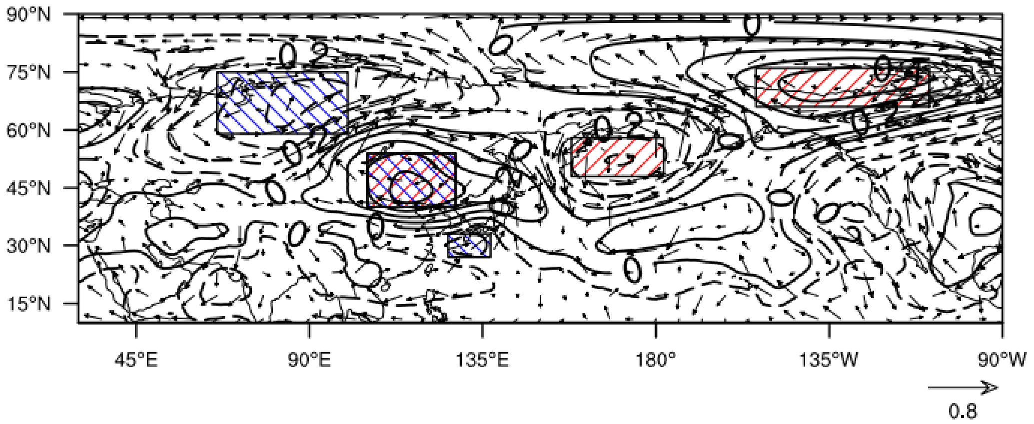

Figure R2. Correlation coefficients between the May Sea ice index and JJA mean geopotential height at 500 hPa (contour) and JJA mean wind at 200 hPa (arrow) from 1979 to 2017. Regions of red (blue) oblique lines mean the centres of the TP_{WP} (TP_{EU}), which were used to calculate the Rossby wave index. The linear trend was moved. The atmospheric data used were ERA-interim data sets.

Related References:

Wang, H. J. and He, S. P.: The North China/Northeastern Asia Severe Summer Drought in 2014, J. Climate, 28, 6667–6681, https://doi.org/10.1175/JCLI-D-15-0202.1, 2015.

Yin, Z. C., Yuan, D. M., Zhang, X. Y., Yang, Q., and Xia, S. W.: Different contributions of Arctic sea ice anomalies from different regions to North China summer ozone pollution, Int. J. Climatol., 40, 559–571, https://doi.org/10.1002/joc.6228, 2020.

Revision:

Lines 98-99: Modified from Wang and He (2015), Yin et al. (2020a) calculated the summer EU index as follows:

3. L111-112: I don't think winds at 10m can be used to represent the transport from Yangtze river Delta to North China. Moreover, lifetimes of O_3 precursors are generally within a few hours in summer. Any reference to support this argument?

Reply:

<u>With GEOS-Chem model</u>, Gong et al. (2020) found strong anomalous southerlies prevailed in central eastern China could bring O_3 and its gaseous precursors from central eastern China to North China (Figure R3). They also verified that reductions in VOC_S (NO_X) in central eastern China could reduce the MDA8 O_3 concentrations averaged over North China by sensitivity experiments.

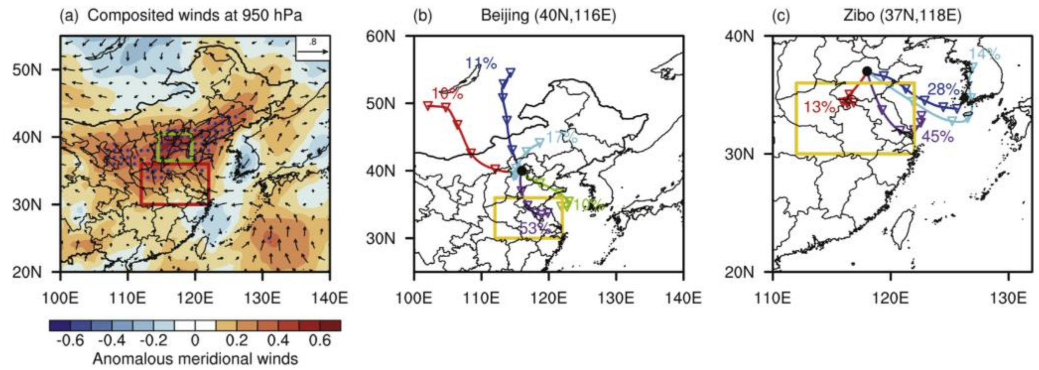

Figure R3. Winds that transport O_3 from central eastern China to North China during OPEs5. (a) Composites of anomalous wind fields at 950 hPa during OPEs5 in North China relative to the seasonal-mean over May-July in 2014-2018. The daily time series of wind in each grid is standardized by the standard deviation. Shades indicate anomalous meridional wind speeds during OPEs5 relative to seasonal-mean. Blue dots indicate grids with statistically significant differences in meridional wind speed at 99% confidence level. The North China and central eastern China are enclosed by green and red rectangles, respectively. (b)-(c) Five-day backward trajectories of the air mass at two cities (Beijing and Zibo) in North China for days of OPEs5 over May-July in 2014-2018. The trajectories are retrieved at 2:00, 8:00, 14:00 and 20:00 GMT +8 for each day during the OPEs5. Inverted triangles appear every 24 h on each trajectory. The percentages with different colors indicate the frequencies of different trajectories. The yellow rectangle encloses central eastern China.

With observations, Yin et al. (2019) found anomalous southerlies (associated with cyclonic anomalies to the west and anticyclonic flow to the east) from the Yangtze River transported O_3 precursors and superposed them with the local high emissions in North China.

Related References:

Gong, C., Liao, H., Zhang, L., Yue, X., Dang, R. J., and Yang, Y.: Persistent ozone pollution episodes in North China exacerbated by regional transport, Environ. Pollut., 265, 115056, https://doi.org/10.1016/j.envpol.2020.1 15056, 2020.

Yin, Z. C., Wang, H. J., Li, Y. Y., Ma, X. H., and Zhang, X. Y.: Links of climate variability among Arctic Sea ice, Eurasia teleconnection pattern and summer surface ozone pollution in North China, Atmos. Chem. Phys., 19, 3857–3871, https://doi.org/10.5194/acp-19-3857-2019, 2019.

Revision:

Lines 114-116: (1) anomalous southerlies (expressed by V10mI) transported O_3 precursors from Yangtze River Delta and superposed them with the local high emissions in North China **(Yin et al., 2019; Gong et al., 2020)**……

4. L113: Rain shouldn't be effective to remove ozone. You also confirmed this in L127.

Reply:

Rain doesn't directly influence ozone by the process of wet deposition. More precipitation indicated the ultraviolet radiations were prevented by more cloud cover and then the photo-chemical reactions would be weakened. Therefore, precipitation indirectly influenced the surface ozone through cloud cover and radiation. The relevant physical explanations have been supplemented in the revised version.

Revision:

Lines 116-117: (2) More precipitation indicated **more cloud cover** and stronger efficiency of sunlight blocking (–PI); (3)Cooler……

Lines 270-272: Sinking heating, intense sunlight (Figure 7c) and less precipitation (**correspondingly more cloud and weaker ultraviolet radiations**, Figure 7a) resulted in beneficial environments for the natural emissions of O_3 precursors (Lu et al., 2019) and photochemical reactions (Pu et al., 2017).

5. L130-132: How about emissions outside of China? Are they fixed at a certain year

or changing over time?

Reply:

The emissions outside of China were also fixed at the year of 2010. It didn't change over time, and just the meteorological conditions would change over time. The scope of fixed anthropogenic emissions used in GEOS-Chem model was shown in Figure R4.

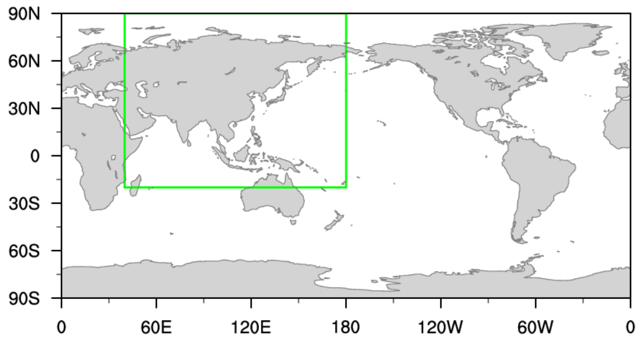

Figure R4. The scope of fixed anthropogenic emissions (green box).

6. L141&L217: The subtitles are not clear.

Reply:

The subtitle "Robust and changing connections" is revised to "Changing connection between OWI and SC_{WS}", and the subtitle "Possible physical mechanisms" is revised to "Physical mechanisms".

Revision:

Line 145: Changing connection between OWI and SC_{WS}.

Line 222: Physical mechanisms

7. L169&Fig1c: Why is ozone strongly enhanced over the whole domain? There should be weak ozone formation over the high-latitude region with few emissions.

Reply:

(1) Figure 1c showed **the anomalies of ozone concentrations** (i.e., composite differences) rather than the actual ozone concentrations. It had little to do with the ozone itself.

(2) Figure 1c just reflected the impact of meteorological conditions. As shown by Figure R5, the region near Lake Baikal was **controlled by anticyclone anomalies**. Under this kind of atmospheric circulation, **favorable meteorological conditions** were

conducive to the formation of ozone.

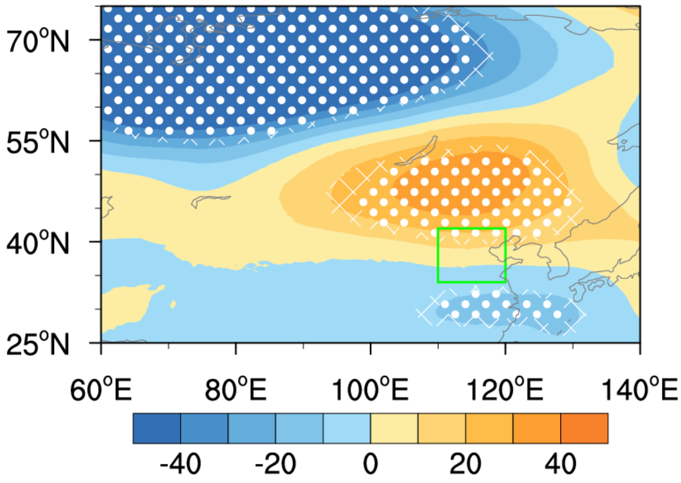

Figure R5. Composite difference of the geopotential height at 500 hPa (unit: gpm) in summer between the six highest and the six lowest EU index years from 1980 to 2018. The white dots (hatching) indicate that the difference was above the 95% (90%) confidence level (t test). The green box represents the location of North China.

(3) As the reviewer mentioned, the ozone concentrations over the high-latitude region were relatively low. Therefore, we didn't pay much attention to the high-latitude region, and the main focus was still North China.

8. L211-212: Should be corrected.

Reply:

The sentence "However, changed from SC_{WS} in P1 to SI_{GR} in P2 (Figure 3 c, d)." is revised to "However, the preceding factors inducing the EU pattern to influence the O_3 pollution in North China changed from SC_{WS} in P1 to SI_{GR} in P2 (Figure 3 c, d).".

Revision:

Lines 215-216: However, **the preceding factors inducing the EU pattern to influence the O_3 pollution in North China** changed from SC_{WS} in P1 to SI_{GR} in P2 (Figure 3 c, d).

9. L218: Please add "of" before "how to…".

Reply:

The "of" has been added before "how to…".

Revision:

Line 223: The physical mechanisms **of** how to achieve the impacts of SC_{WS} on surface

O_3 pollution in North China is still a new question to the best of our knowledge.

10. Discussion: Further studies using climate-chemistry model to verify the role of snow cover should be highlighted.

Reply:

The attention of using climate-chemistry coupled model to verify the role of snow cover on summer ozone pollution in North China is supplemented in the discussion.

Revision:

Lines 348-349: Moreover, the climate-chemistry coupled model need be used to verify the role of snow cover on ozone pollution in North China in further studies.