The response of the North Pacific jet and stratosphere-to-troposphere mass transport over western North America to RCP8.5 climate forcing

Dillon Elsbury[1,2] Amy Butler[2] Melissa Breeden[1,3] John Albers[1,3]
[1]Cooperative Institute for research in Environmental Sciences
[2]National Oceanic and Atmospheric Administration Chemical Sciences Laboratory
[3]National Oceanic and Atmospheric Administration Physical Sciences Laboratory

- Enhanced stratosphere-to-troposphere (STT) transport of ozone may occur with climate change
- Why? The amount of ozone contained in stratospheric intrusions is linearly/positively related to the amount of ozone in the lower stratospheric reservoir (e.g., along 350 Kelvin isentrope)
    - The amount of ozone in the reservoir will likely increase
- How will this influence STT over western North America, which is a global hotspot for intrusions of stratospheric air deep into the troposphere?

WACCM Experiments	SST years	GHG years	Methane (ppb)	Nitrous oxide (ppb)	Carbon dioxide (ppm)
Preindustrial	1840-1870	1850	788	275	285
RCP8.5	2070-2090	2090	3625	421	844
RCP8.5 SSTs	2070-2090	1850	788	275	285
Details: 60 year continuous integrations, fully interactive chemistry, inactive ocean/sea ice, “time-slice” simulations with fixed boundary conditions, tracer of stratospheric ozone (O3S)					

In present times, the annual cycle of the North Pacific jet influences STT over western North America with deep STT peaking during spring, the *spring transition*

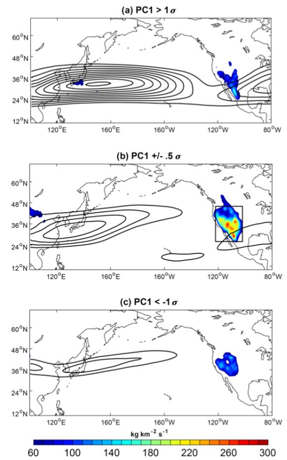
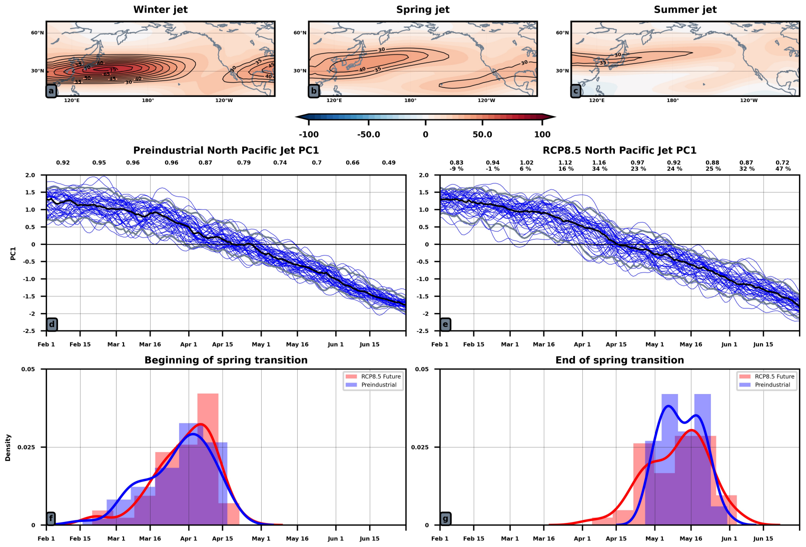


Figure 4. Composite STT-PBL during the three jet phases using ERA-Interim PC1 for 1980–2016. **(a)** STT-PBL during days characterized by a wintertime value ($N = 998$); **(b)** STT-PBL during days characterized by a transitional PC1 value ($N = 952$); **(c)** STT-PBL during days characterized by a summertime PC1 value ($N = 1125$). Zonal wind contours start at $30\,\mathrm{m\,s^{-1}}$ at intervals of $5\,\mathrm{m\,s^{-1}}$.



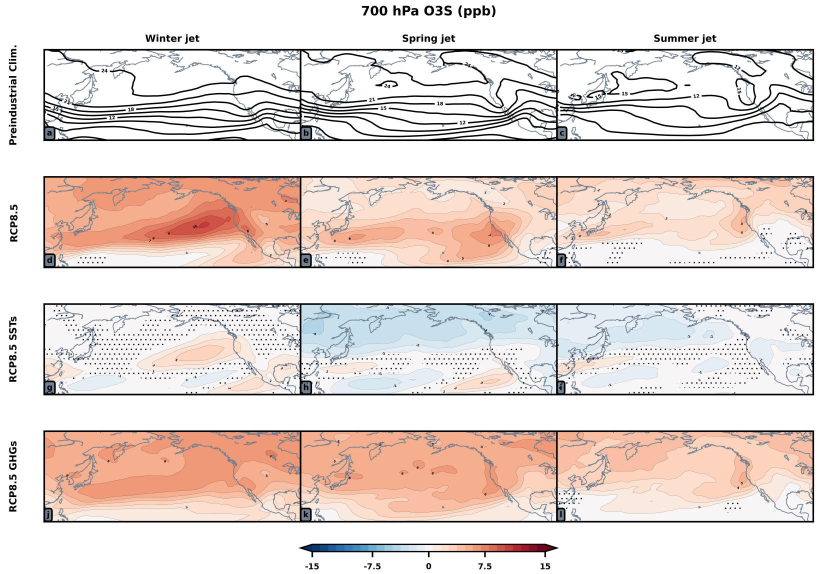
We use the leading EOF1 and principal component (PC1) time series of the daily mean 200 hPa zonal wind averaged over the North Pacific to track the seasonal evolution of the North Pacific jet. This time evolution is shown in panel (d) for the preindustrial control and panel (e) for the RCP8.5 experiment. Composites of the jet during the various phases are shown in panels (a), (b), and (c).

Winter jet:
PC1 > 1
Spring transition:
PC1 < 0.5 and PC1 > -0.5
Summer jet:
PC1 < -0.5

Key results
Preindustrial control does a good job characterizing annual cycle of the jet. There is no statistically significant change in the timing of the spring transition in response to RCP8.5 forcing. However, the jet has far more variability during future spring and future summer than in the preindustrial control.

Bottom left three panels from: Breeden, M. L., Butler, A. H., Albers, J. R., Sprenger, M., & Langford, A. O. N. (2021). The spring transition of the North Pacific jet and its relation to deep stratosphere-to-troposphere mass transport over western North America. *Atmospheric Chemistry and Physics*, *21*(4), 2781-2794.

Future GHGs increase lower tropospheric O3S with secondary role played by future SSTs

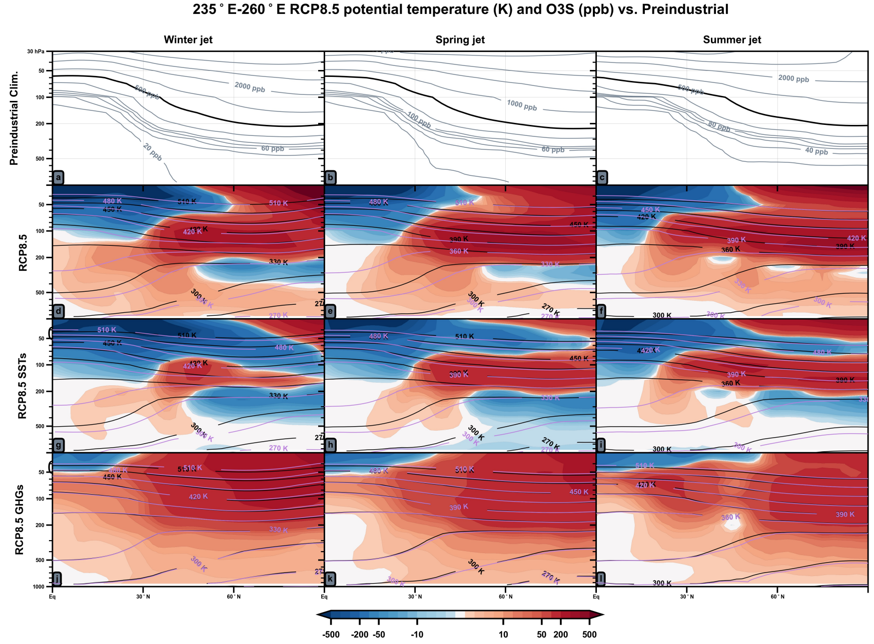


The 700 hPa O3S preindustrial control climatology is shown in the first row, the RCP8.5 O3S response in the second row, the RCP8.5 SST O3S response in the third row, and the RCP8.5 GHG O3S response in the fourth row. Non-stippled grid points are statistically significant at a 5% significance threshold using a student’s t-test. Each column corresponds to a different stage of the annual cycle evolution of the North Pacific jet stream.

Model climatology
Climatological lower tropospheric O3S peaks over western North America in the preindustrial control during boreal spring. Note the anticyclonic (cyclonic) rotation of the isopleths over the North Pacific (North America).

Key results
Future lower tropospheric O3S over western North America responds most strongly to the RCP8.5 GHGs. This is true for the entire northern hemisphere (not shown). While the RCP8.5 SSTs are not primarily responsible for the lower tropospheric O3S change, they are primarily responsible for the change in the large-scale atmospheric circulation, namely changes in synoptic to planetary scale wave behavior. These regional wave responses forced by the RCP8.5 SSTs elicit more zonally asymmetric O3S responses compared to the RCP8.5 GHGs.

Future SSTs modify the large-scale atmospheric circulation making STT of O3S more likely, but again, it is the future GHGs increasing lower tropospheric O3S over the region



The preindustrial control climatology of O3S averaged zonally over western North America is shown in the first row, the RCP8.5 response in the second row, the RCP8.5 SST response in the third row, and the RCP8.5 GHG response in the fourth row. Column one is associated with the late winter jet stream, column two is associated with the spring jet, and column three is associated with the summer jet stream. In the bottom three rows, preindustrial control isentropes are overlaid in black and the anomalous isentropes are overlaid in purple with intervals of +/- 30 Kelvin for both.

Model climatology
Of the three seasons, O3S is most abundant in the extratropical lower troposphere during winter. Lower stratospheric O3S mixing ratios are larger during winter and spring as opposed to summer when the entire distribution of O3S shifts upward towards higher altitudes

Key results
RCP8.5 GHGs promote the enhancement of O3S over western North America. Both the RCP8.5 GHGs and SSTs enhance the amount of O3S in the extratropical lower stratospheric reservoir. This is because both forcings accelerate the shallow branch of the Brewer Dobson Circulation, which redistributes O3S from the tropical stratosphere to the high-latitude stratosphere. Enhanced STT may occur because the RCP8.5 SSTs depress the isentropes deeper into the troposphere.