Trends and interannual variabilities of CO and aerosols in the upper troposphere and their connections to the Asian summer monsoon, climate variability, and surface emissions

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Asian summer monsoon (ASM) dynamic system

- The Asian summer monsoon (ASM) is a major component in the climate system. It transports aerosols and trace gases from the most polluted regions in Asia to the upper troposphere (UT) where they spread out by the dynamic ASM anticyclone (ASMA) to regions far beyond Asia

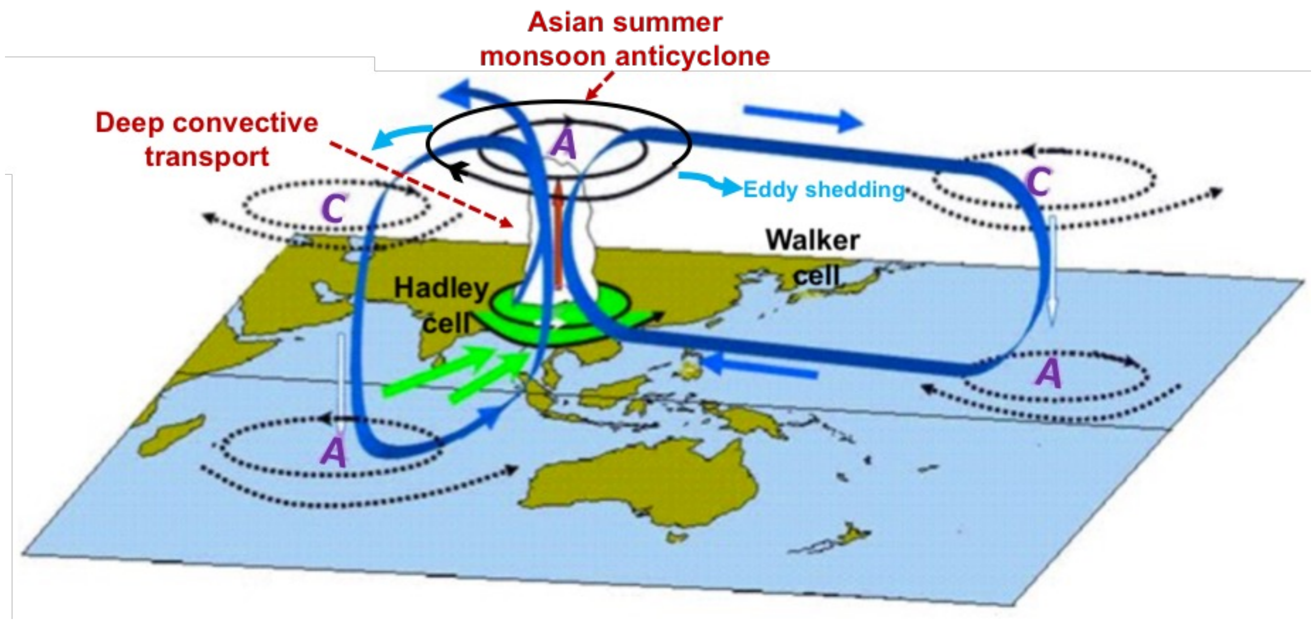
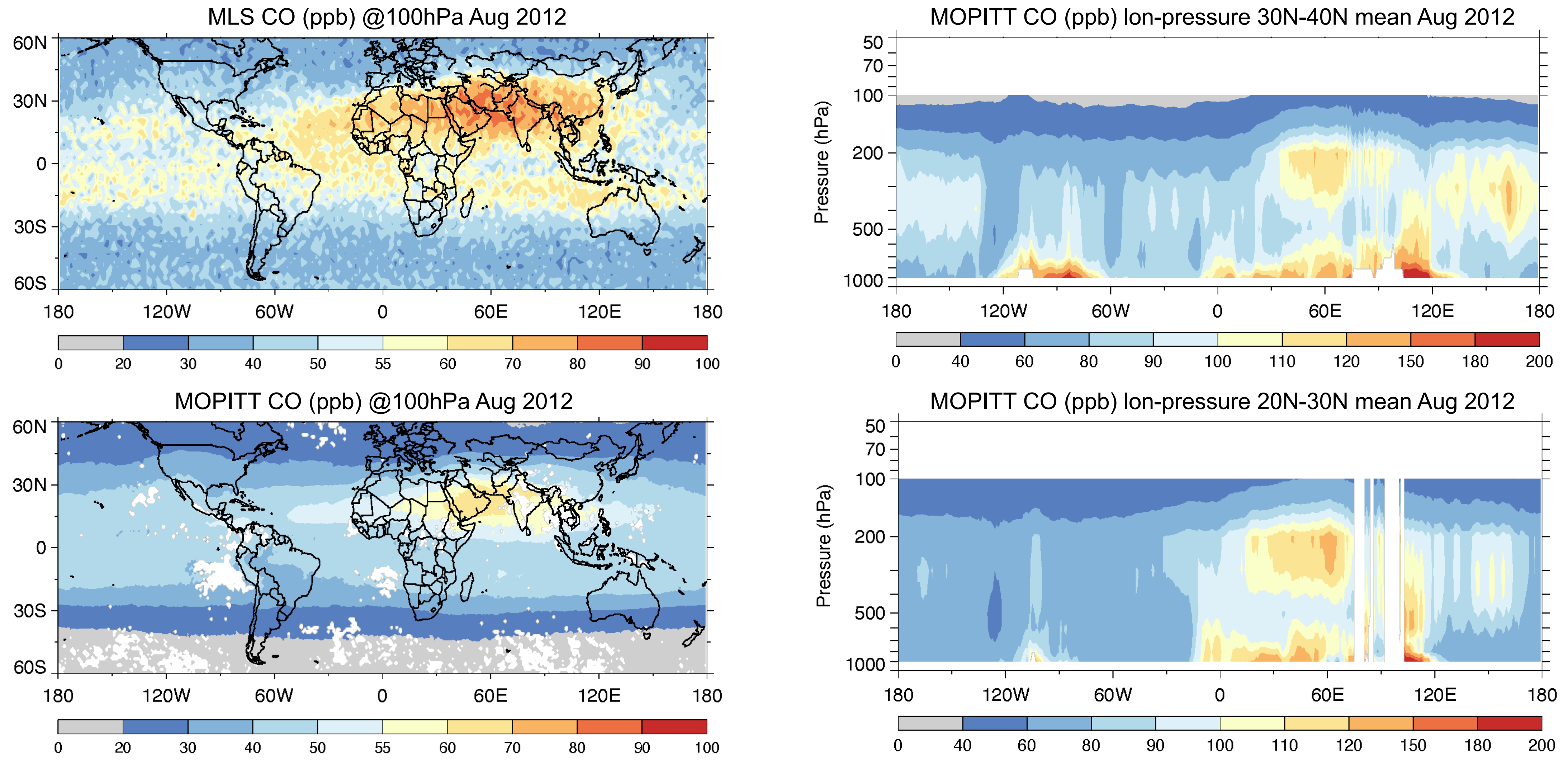


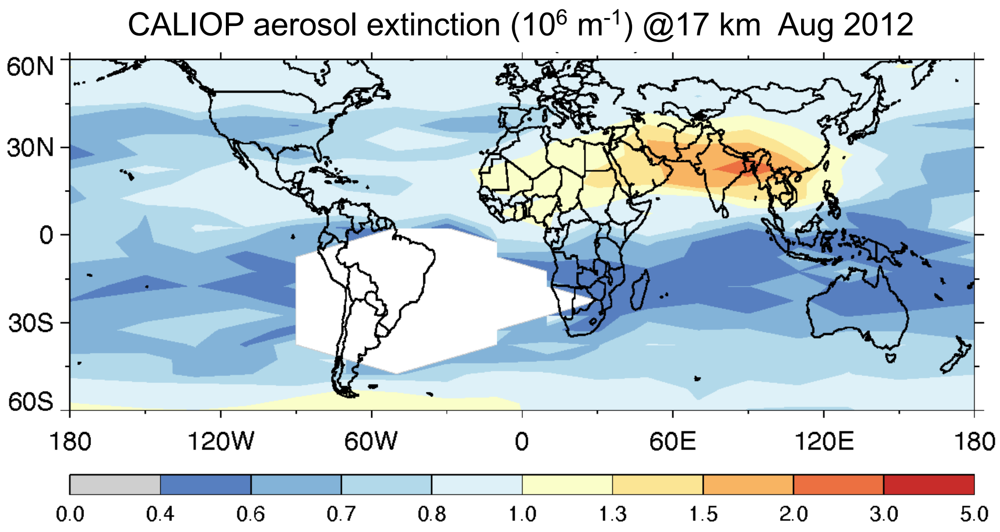
Figure adapted from: https://www.clivar.org/asian-australian-monsoon

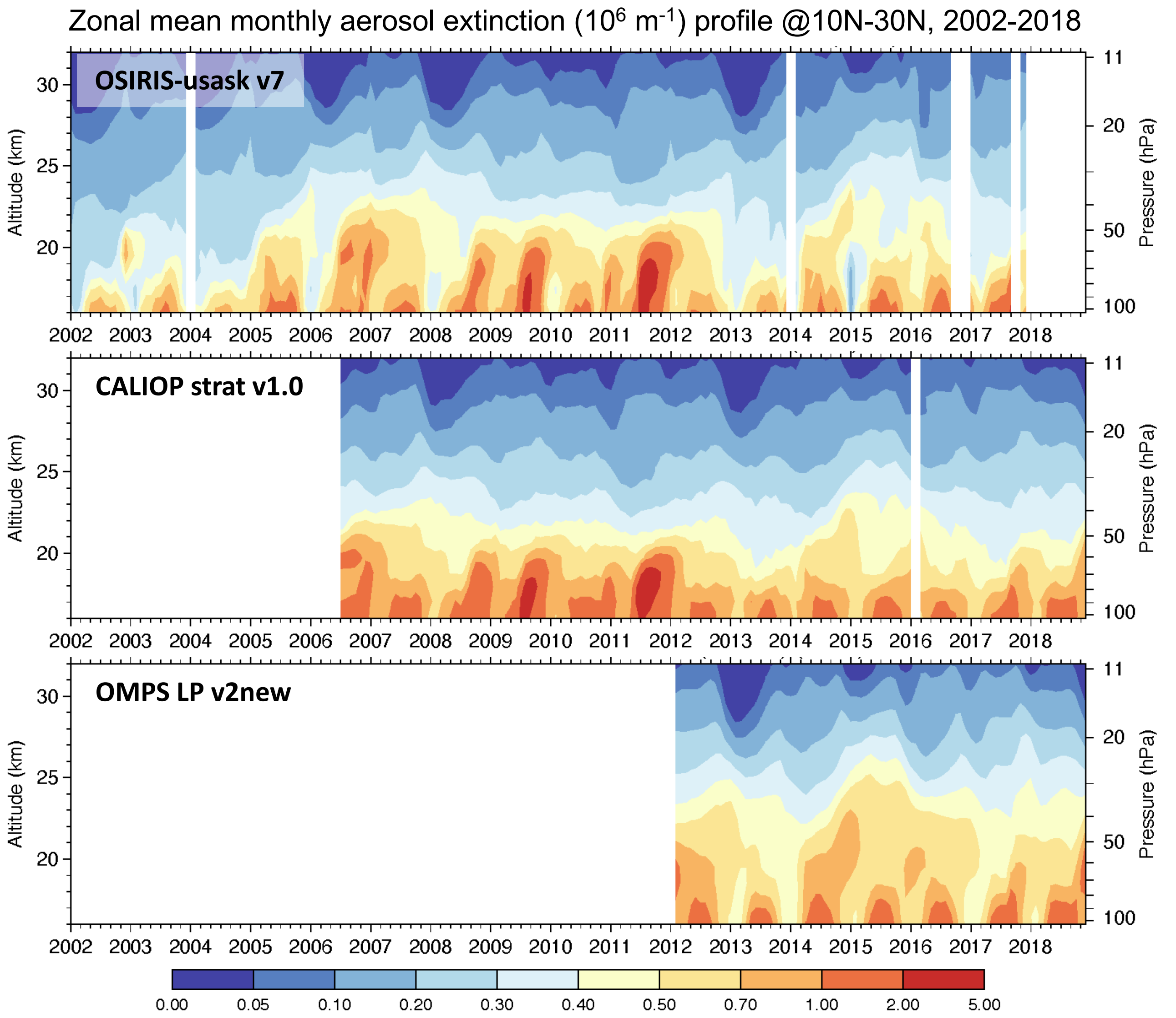
- ASM connects to other weather and climate systems, such as walker and Hadley cell circulations, with significant spatial and temporal variability ranging from weather scale to multi-year climate scale

Observational evidence of ASM transport of CO from satellite data



Observational evidence of ASM transport of aerosols from satellite aerosol extinction data





- Although aerosols are soluble species that can be removed by the monsoon precipitation, there are clear evidence of convective transport to the UTLS
- Satellite retrievals at the tropopause region are most difficult because the interference of the thin ice clouds

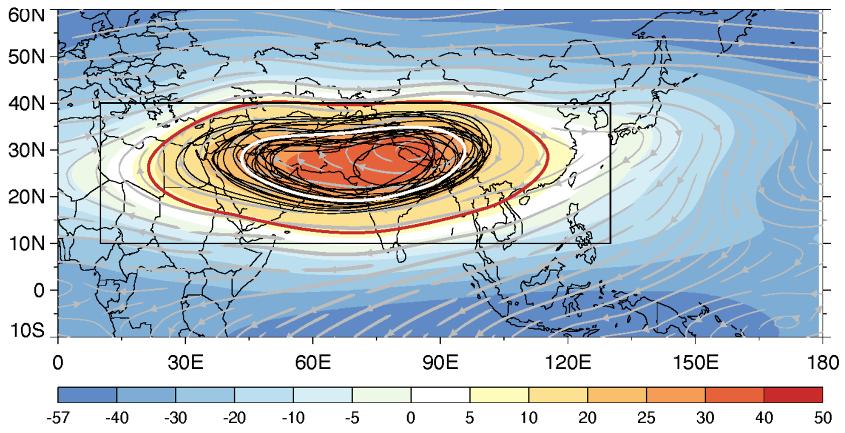
We use the NASA GEOS model together with MERRA-2 reanalysis of meteorological fields and satellite observations to examine:

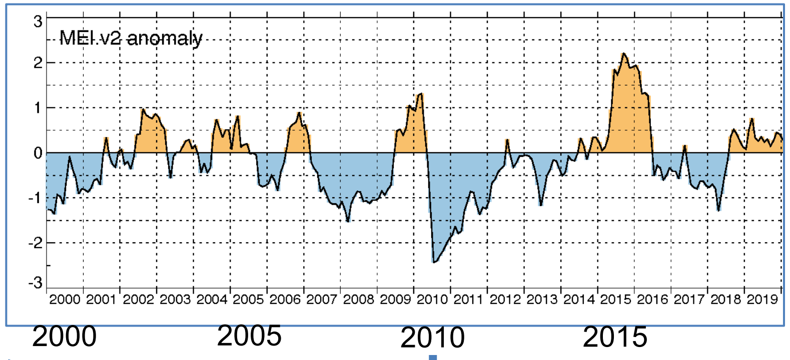
1) Interannual variabilities of summertime CO and aerosols in the UT (150 hPa) and their connections to the variabilities of ASMA (defined by stream function), magnitude of convective transport (referred by a transport tracer), and ENSO (indicated by Multivariate ENSO Index, MEI.v2)
2) Trends of tropospheric pollutants of CO and aerosols in the UT and their links to the trends of surface anthropogenic emissions and concentrations

- GEOS model set up:
  - 20-year simulation (2000-2019) with emissions from anthropogenic (CEDS v1, aka CMIP6), biomass burning, and other natural sources
  - Including a transport tracer TRCO50 with prescribed, invariant CO sources and fixed 50-day lifetime to attribute the pollutants variability solely do to transport

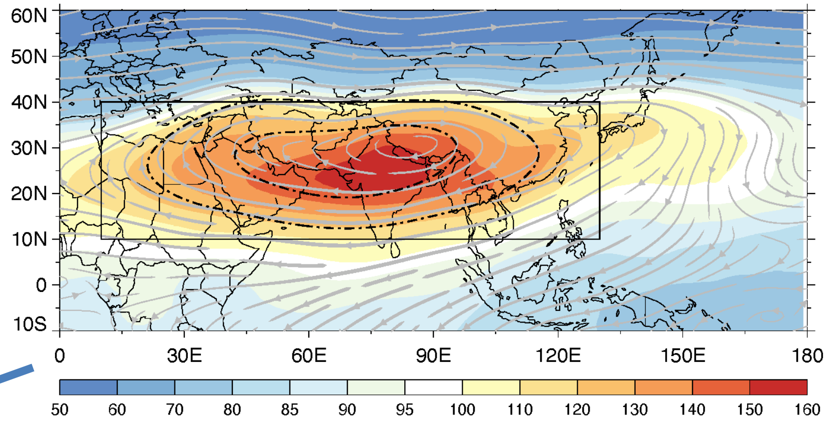
1a) Interannual variability of ASMA and transported pollutants at 150 hPa are closely associated with ENSO

ASMA size and strength defined by stream function

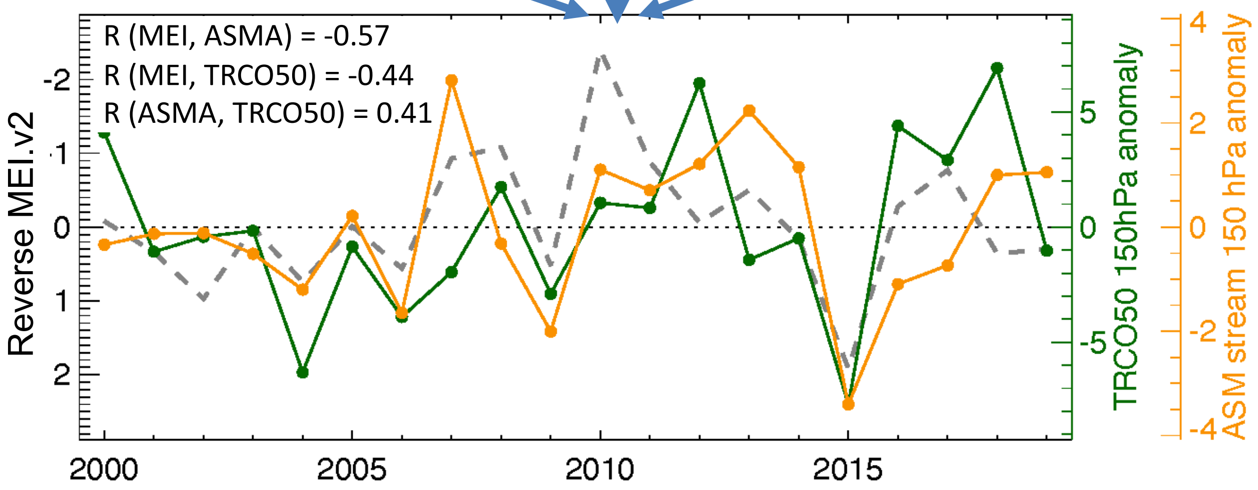




Transport tracer CO50 attributing the change caused by transport alone

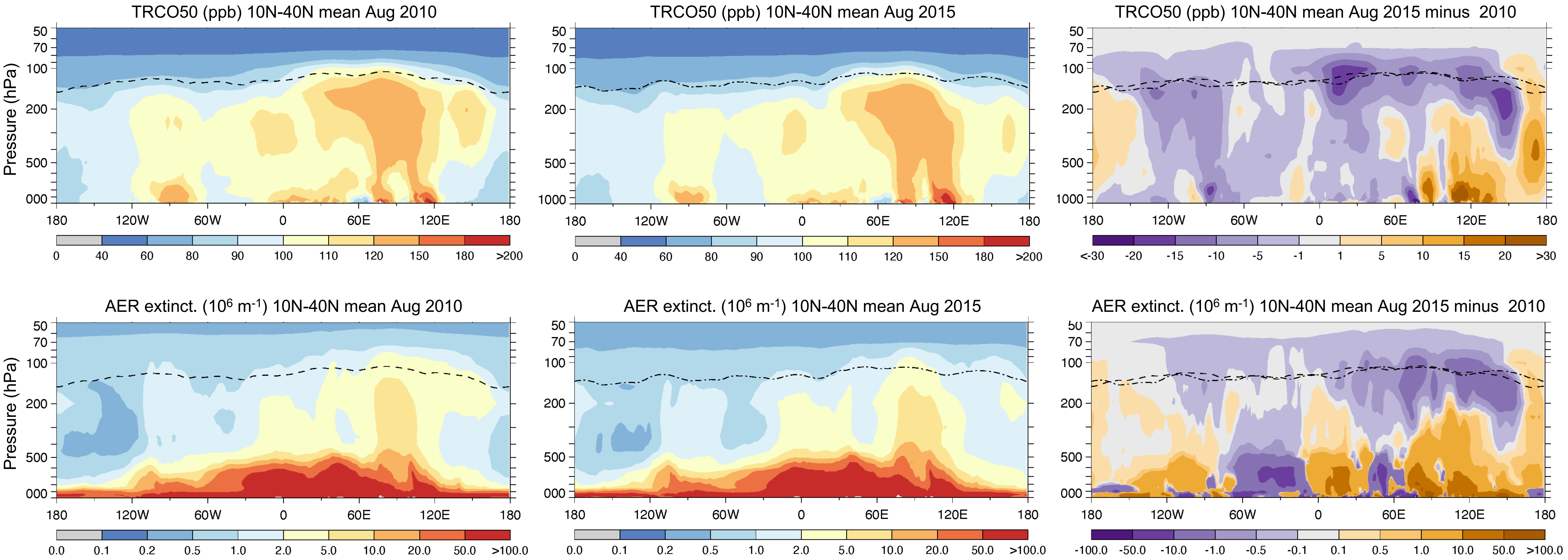


- Both ASMA (STRM) and TRCO50 at 150 hPa are negatively correlated with MEI in boreal summer
- No statistically significant trends of ASMA and TRCO50 in 2000-2019 at 150 hPa



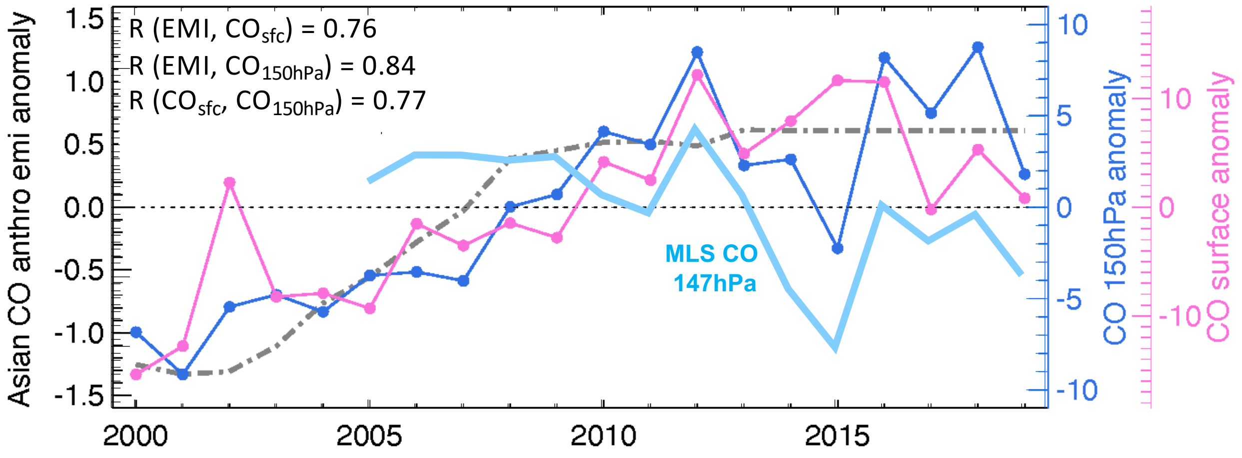
- In general, TRCO50 concentrations at 150 hPa in the ASMA area are lower in El Niño years and higher in La Niña years

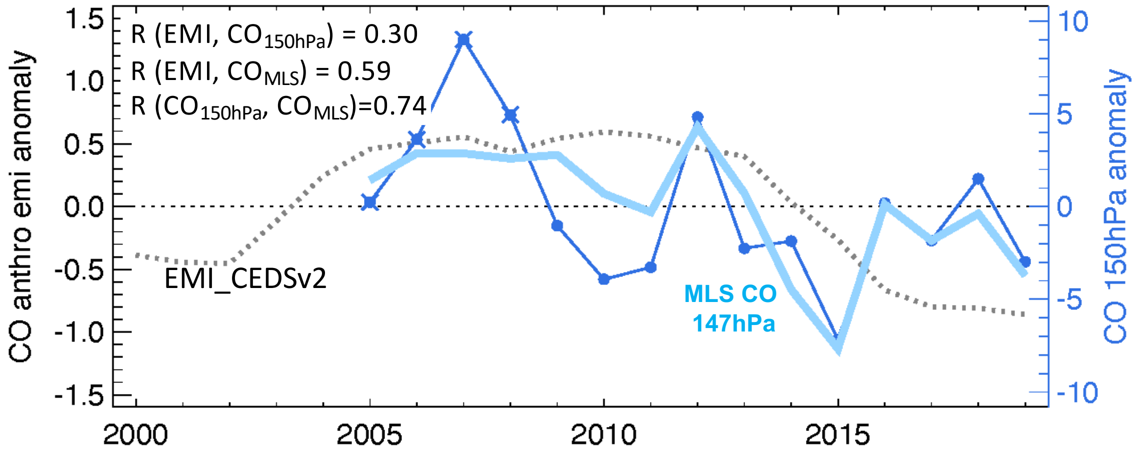
1b) Convective transport by ASM: La Niña (2010) vs. El Niño (2015)



- Both TRCO50 and aerosols showing features of contrasts between 2015 (strong El Niño year) and 2010 (strong La Niña year), with more pollutants accumulated below ~200 hPa but less transported to above 200 hPa, and stronger transport to the Pacific in the entire troposphere and lower stratosphere in 2015
- Aerosols decrease with altitude much faster than TRCO50 (and CO) because of their loss by wet scavenging

2) Trends of CO at 150hPa over the ASMA region and connections to surface emissions and concentrations





CO trends at the surface and at 150 hPa compared to the anthropogenic emission trends in Asia:

- Model simulated statistically positive trends of CO concentrations at both surface and 150 hPa follow the trend of CEDS v1 anthropogenic emission used in the model
- However, MLS observed CO at 147 hPa showing an opposite temporal trend to the model trend that is a statistically significant negative trend from 2005 to 2019 ($p = 0.011$ from the student t-test)
- The opposite trends of CO between MLS and model at ~150 hPa since 2005 can be mostly explained by the incorrect temporal trends of the Asian anthropogenic CO emission used by the model, as another simulation using the CEDS v2 (2021 release) suggested. We are currently rerun the model simulations with the CEDS v2 emissions (after correcting some inconsistencies in set up)

Concluding remarks

- There are significant interannual variabilities of ASMA strength/size and convective transport efficiencies as indicated by TRCO50, both are negatively correlated with MEI at 150 hPa (R = 0.4-0.6 during 2000-2019). The pollutants-MEI relationships in the middle troposphere and over the N Pacific are expected to be different than that in the UT (will examine)
- There is no statistically significant trends of ASMA strength/size (indicated by the stream function) and convective transport strength (indicated by the TRCO50) to the UT in the past two decades
- The interannual variability of tropospheric pollutants over ASMA in the UT responds to the weather/climate variability, but the decadal/multi-decadal trends are controlled mostly by the anthropogenic emission