National Aeronautics and Space Administration

Characterizing intraseasonal and interannual variability in the composition of the Asian summer monsoon anticyclone using Aura Microwave Limb Sounder measurements

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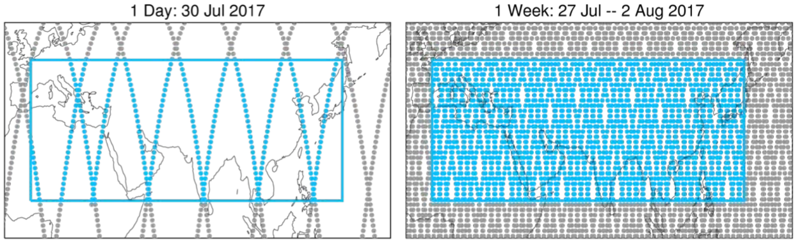
- The **Microwave Limb Sounder (MLS)**, launched as part of NASA's Aura mission in July 2004, makes simultaneous co-located measurements of trace gases and cloud ice water content (IWC, an indicator of deep convection) in the UTLS on a daily basis

- MLS obtains ~300 measurements each day in the general region of the Asian summer monsoon (ASM), which we define here to be the area enclosed within the 10°–50°N latitude × 0°–140°E longitude "box"



- With its relatively dense spatial and temporal sampling, extensive measurement suite, and insensitivity to aerosol and all but the thickest clouds, MLS is well suited to investigating UTLS composition in the ASM region and quantifying its spatial and seasonal variations

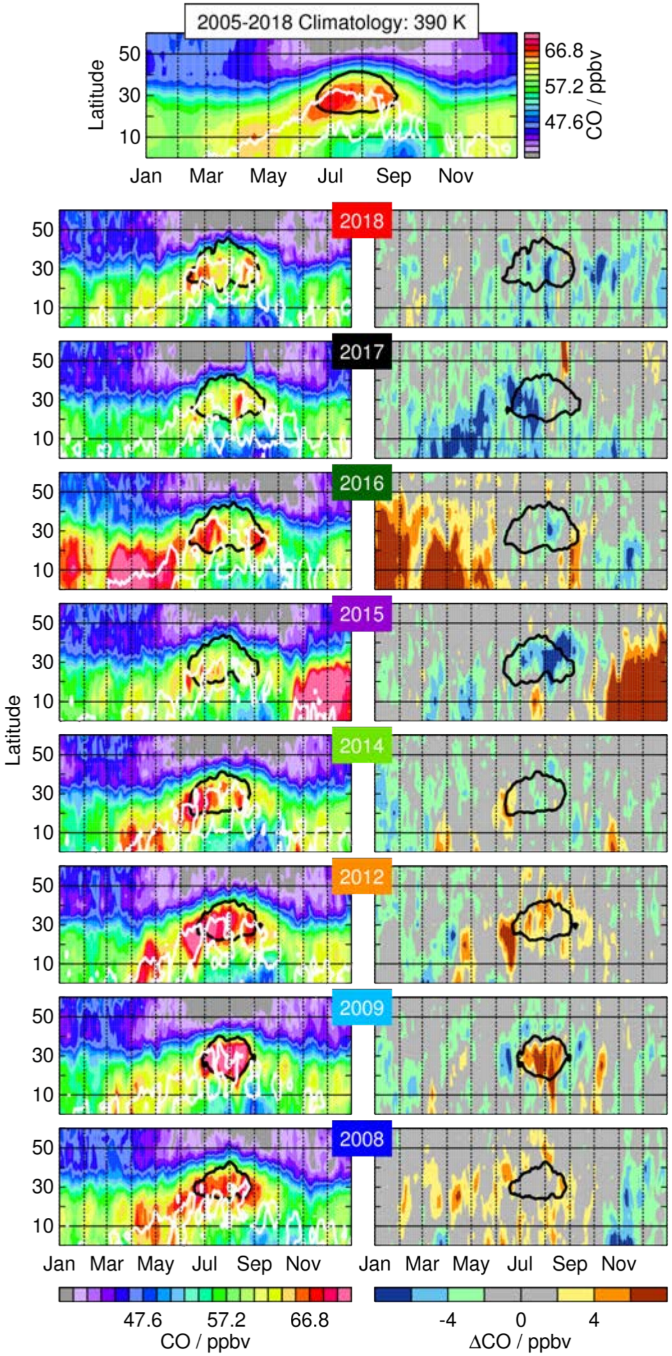
- Recently, we used 10 years of MLS data to characterize the climatological composition of the ASM anticyclone throughout its annual life cycle [Santee et al., *J. Geophys. Res. Atmos.*, 2017]

- With a record that now spans more than 14 years, MLS data are also invaluable for assessing interannual variability

- In July–August 2017, the **StratoClim** campaign took place, operating the Geophysica high-altitude research aircraft from Kathmandu, Nepal to study the ASM

- Here we update the published 10-year (2005–2014) MLS climatology by adding 2015–2018 and use the MLS data to place the 2017 monsoon observed by StratoClim into context

- For simplicity, we focus here on a single potential temperature level: **390 K**
    - Within our ASM box during boreal summer, 390 K corresponds to MLS retrieval pressure levels of 121–82 hPa, or ~15–17 km altitude – just above the tropopause in the subtropics



- Top panel: Time series over the full annual cycle of the 14-year (2005–2018) climatology of MLS CO at 390 K calculated over the longitudes of our ASM box (10°–140°E), plotted as a function of latitude
- Black contour: Montgomery Stream Function (MSF) is used to define the approximate "boundary" of the ASM anticyclone
- White contour: MLS measurements of cloud ice water content (IWC) are mainly sensitive to thick clouds with large particles and thus serve as a reliable proxy for deep convection
- Other panels: Time series of CO abundances (left) and anomalies (deviations from climatology, right) for selected years, shown in reverse chronological order
- As the monsoon enters its mature phase in June, MLS CO shows a strong signature of surface emissions trapped inside the anticyclone
- Although the seasonal evolution of CO is similar every year, the anticyclone exhibits a substantial degree of both intraseasonal and interannual variability

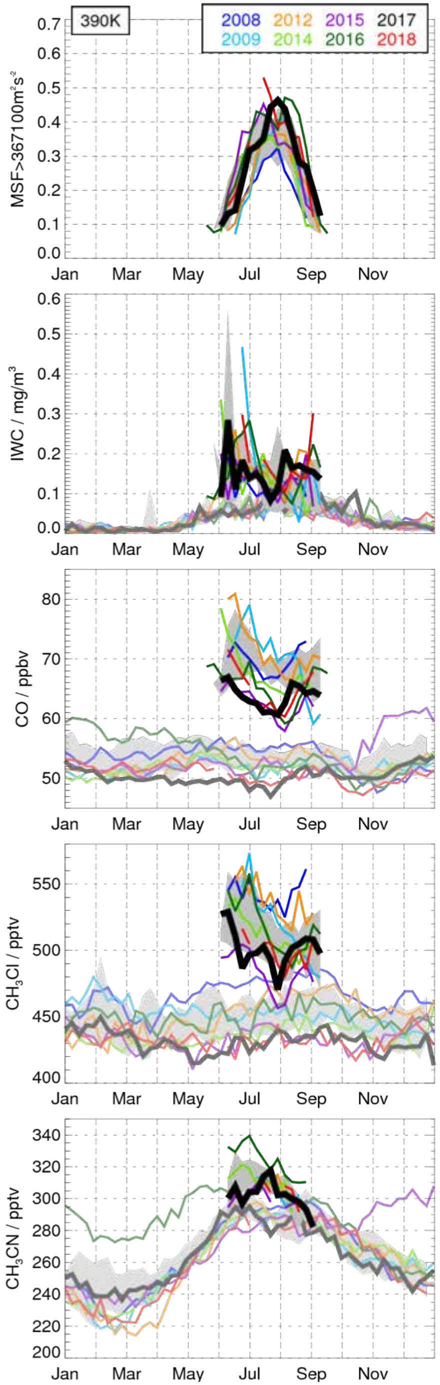
Proxy for anticyclone size

IWC

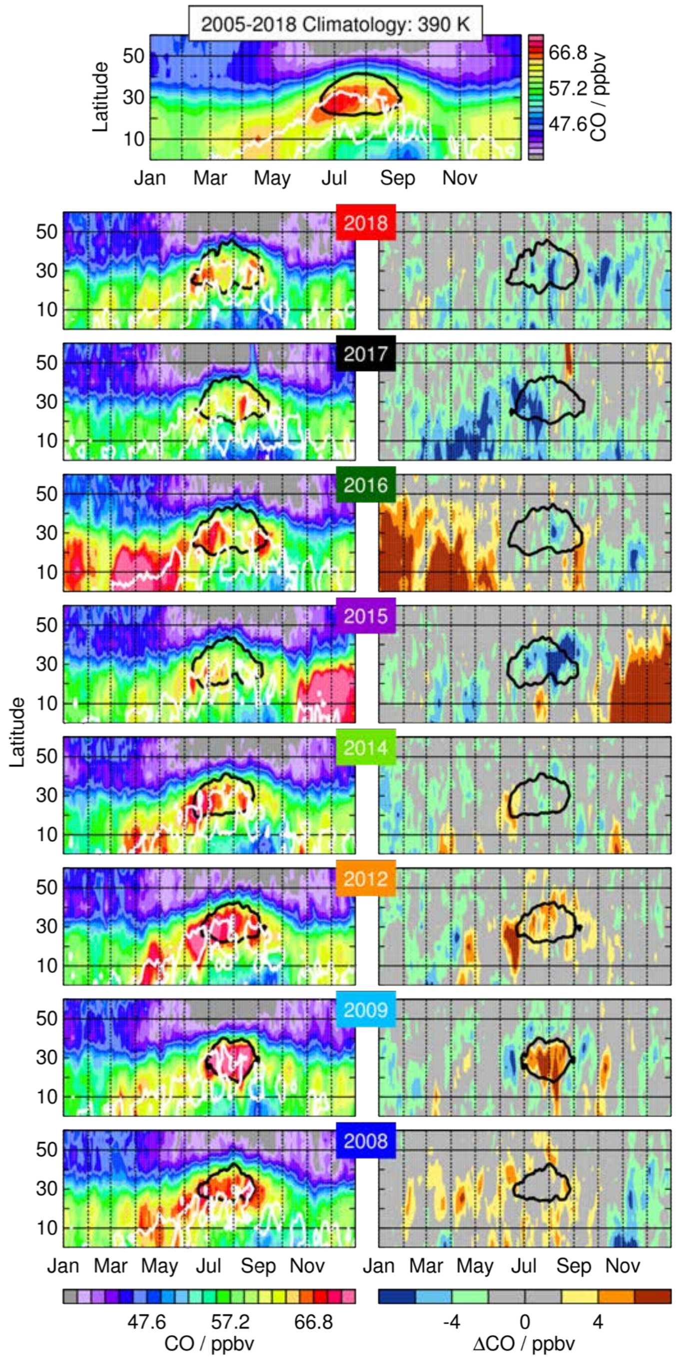
CO

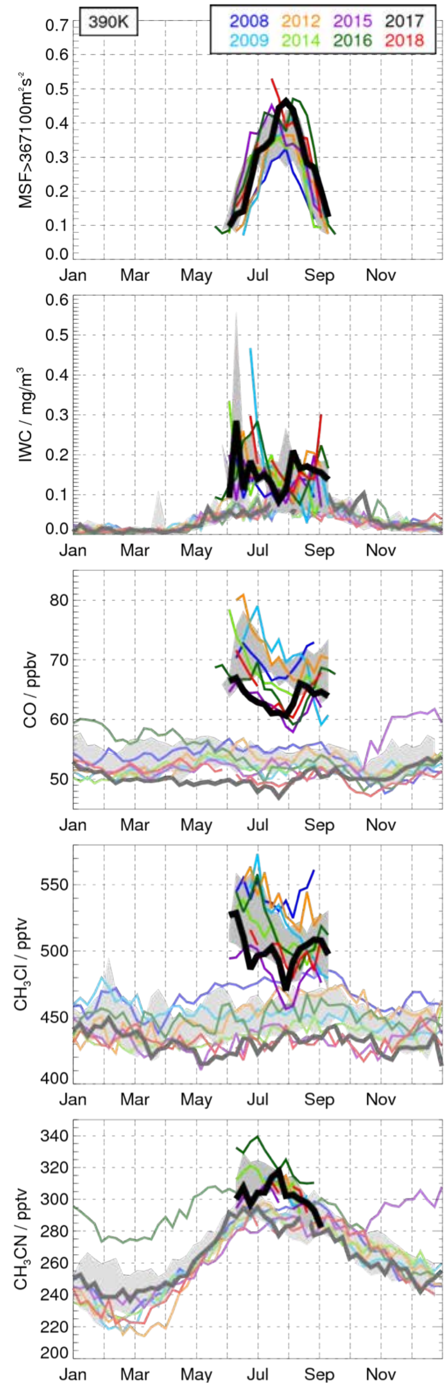
CH_3Cl

CH_3CN

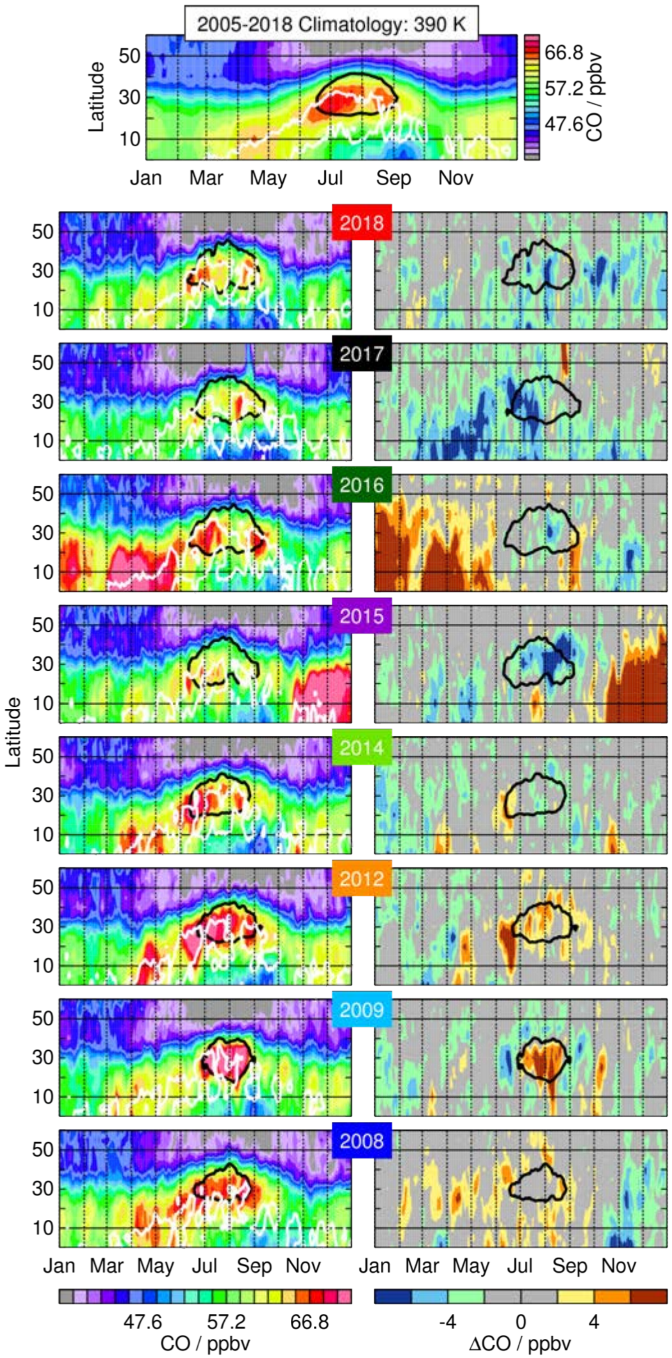


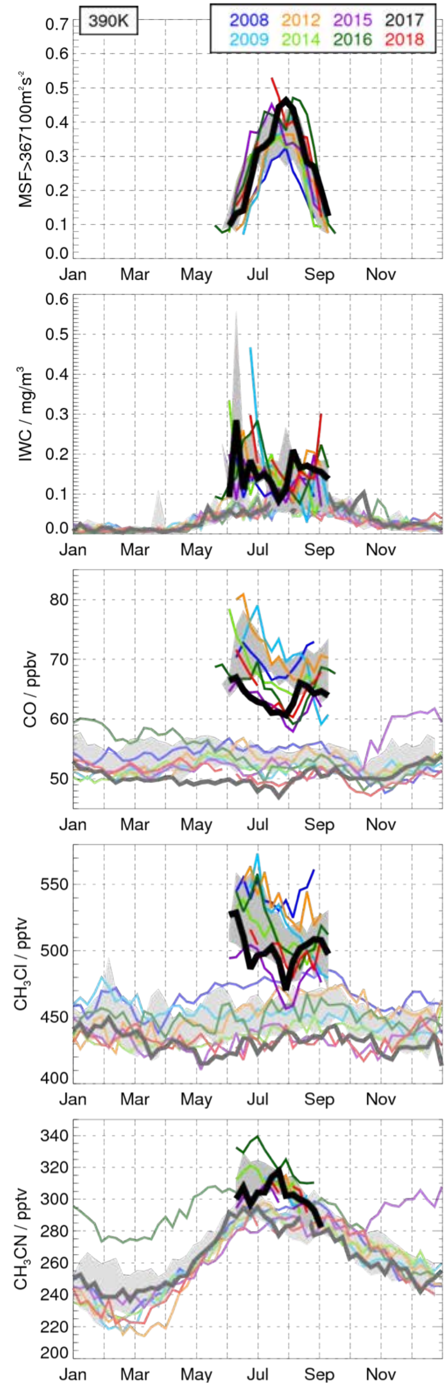
- Top panel: Time series at 390 K of the fraction of MLS data points in the latitude band of our ASM box (10°–50°N) throughout the hemisphere (0°–180°E) that are encompassed within the anticyclone (defined by MSF)
- Grey shading: The envelope of behavior over the Aura mission excluding the highlighted years
- At its peak, the anticyclone fills ~30–50% of the region
- Other panels: Weekly averages of MLS measurements inside the anticyclone (bold colors, darker envelope) compared to those calculated over the rest of the hemisphere outside the anticyclone but still within the latitude range of our box (pale colors, lighter envelope)
- Substantial variability (intraseasonal and interannual) is seen in the strength of deep convection (IWC) and the degree to which the anticyclone is filled with polluted air (CO, CH_3Cl, CH_3CN)
- In this talk we will focus on **2017**, the year of the StratoClim campaign





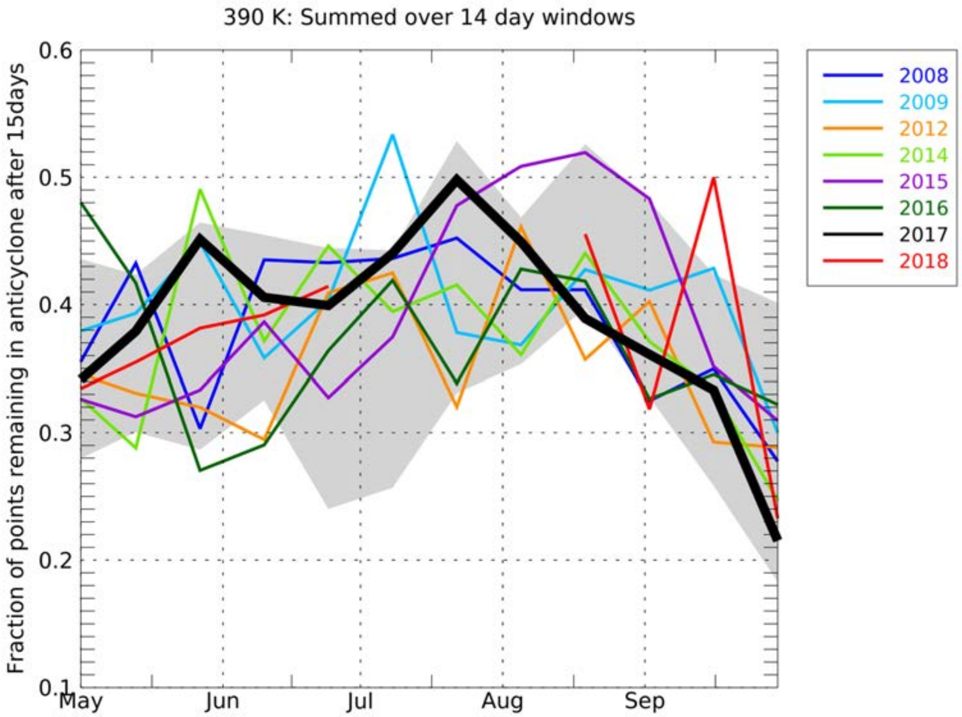
- Initially the **2017** anticyclone was of more or less average size, but it grew to be the largest seen by MLS in late July and remained relatively large thereafter
- A strong and extensive negative anomaly in CO – unique in the MLS record – persisted through much of **2017**, with the latitude-band hemispheric (excluding the anticyclone) averages falling well outside the mission envelope
- Inside the anticyclone, CO values were also markedly smaller than typical for most of the season
- The IWC data indicate that deep convection was slightly weaker than typical during much of June and July but was on the high end of the MLS range in August and early September
- Slightly weak early-season convection cannot fully account for persistently low CO in **2017**



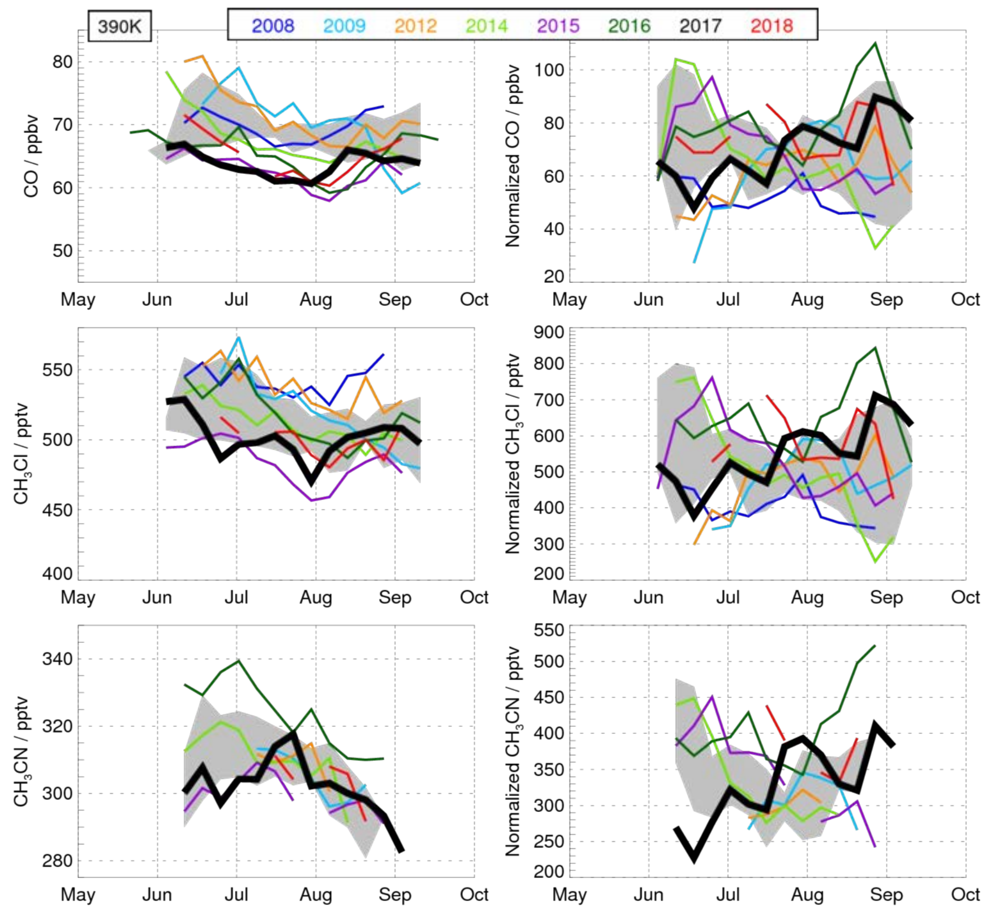


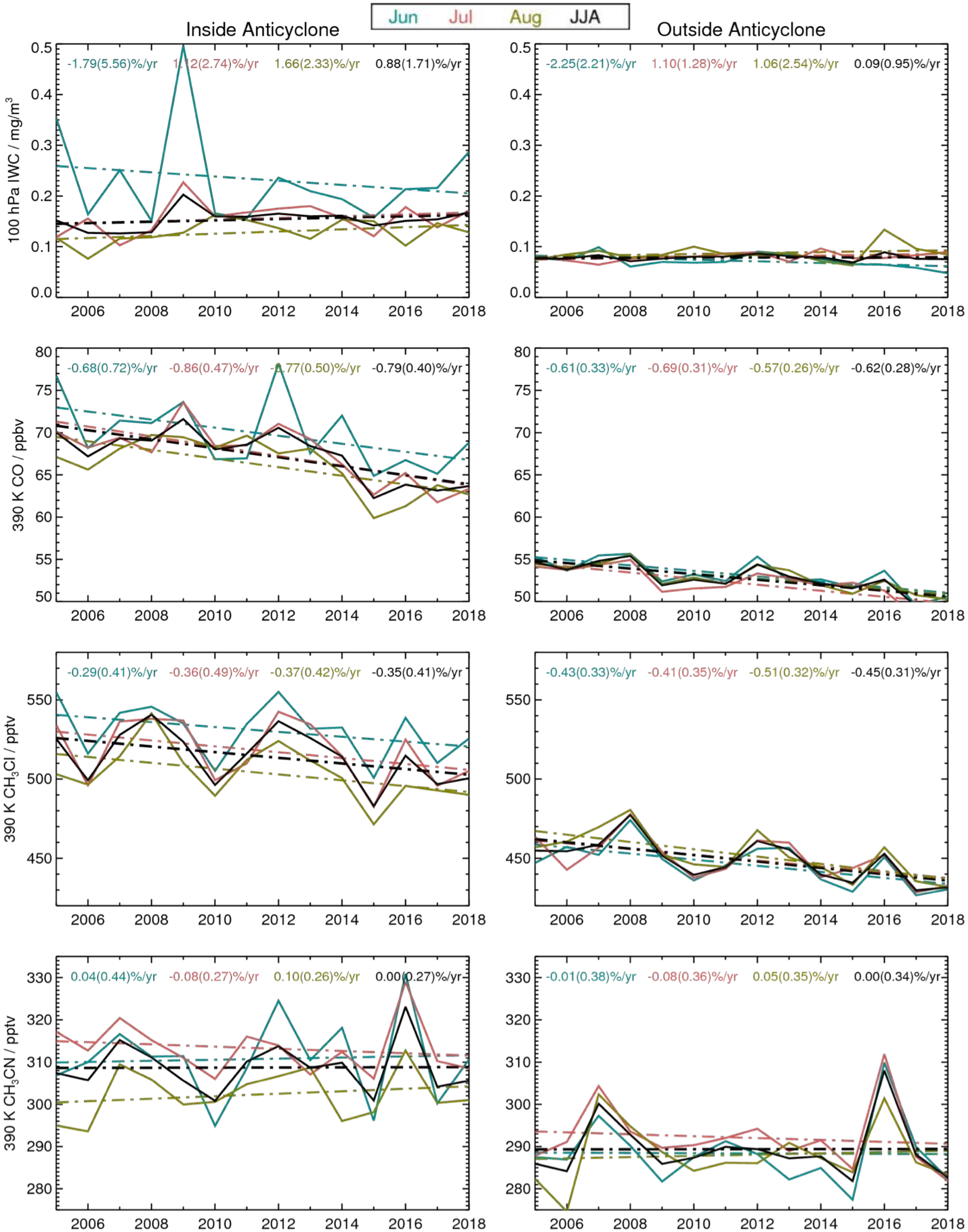
- CH$_3$Cl is produced predominantly by biogenic processes and biomass and biofuel burning, with a small, possibly underestimated, contribution from industry
- Like CO, CH$_3$Cl was smaller than typical both outside and inside the anticyclone in **2017**, although it does not depart from the multi-year envelope as consistently or as substantially as does CO
- CH$_3$CN is produced almost exclusively by biomass burning, with no significant biogenic, biofuel, or industrial sources
- In contrast to CO, CH$_3$CN had essentially climatological values outside the anticyclone in **2017**; inside the anticyclone, although CH$_3$CN was slightly low at first, it reached typical values in July
- Weak fire emissions are unlikely to be the main driver of low CO

- Another factor that should be considered is the permeability of the anticyclone boundary (residence time)
- We use trajectory calculations to quantify the fraction of MLS data points starting off inside the anticyclone each day that still remain inside it 15 days later
- Although the degree of confinement of parcels inside the anticyclone dropped well below average in mid-August, it was relatively high in late July and early August **2017** during StratoClim
- Moreover, the anticyclone provided a robust barrier against leakage in the preceding months, so it seems unlikely that a lack of confinement could account for the much lower anticyclone-averaged CO throughout the season in **2017**



- The area over which pollutants lofted into the anticyclone are dispersed may also be a factor (i.e., a “dilution” effect may occur if the same quantity of pollution is distributed over a broader area in some years than in others)
- We normalize each year’s anticyclone-averaged values by the fraction of points inside the anticyclone that year divided by the climatological fraction of inside-anticyclone points
- When scaled to account for the relative size of the anticyclone in **2017**, the pollution signature was fairly weak early in the season, but the anticyclone was not unusually clean after June
- On the contrary, pollution levels in late July and early August **2017** – when the anticyclone was the largest in the MLS record for that point in the season – were near the top of the MLS envelope





- No significant trend is found in MLS IWC (i.e., convection) in the region
- MLS indicates a decrease in CO of ~0.8 ± 0.4%/yr (2σ) inside the anticyclone; decline outside similar
- These results are broadly consistent with an inversion of MOPITT total column CO, which revealed a significant decrease over East Asia of 0.41 ± 0.09%/yr from 2005 to 2016 that is entirely attributable to a reduction in primary CO emissions in the region, mainly as a result of emission controls in China [Zheng et al., *Environ. Res. Lett.*, 2018]
- CH_3Cl trends are not significant
- CH_3CN shows zero trend in the ASM region, implying little or no change in biomass burning pollution in the UTLS over the 2005–2018 period
- Thus CO is the only pollution marker measured by MLS with a strongly significant trend

- In summary:
  - Aura MLS measures several quantities of relevance for monsoon studies, including species of both tropospheric (e.g., CO, CH_3Cl, CH_3CN) and stratospheric (O_3, HNO_3, HCl) origin, as well as cloud ice water content (IWC, a proxy for deep convection), on a daily basis
  - We have examined 14 years (2005–2018) of MLS data to characterize the climatological composition of the ASM anticyclone and investigate interannual variability in the UTLS response to the monsoon
  - This work provides valuable context for the StratoClim aircraft campaign conducted in 2017
  - The signature of pollution trapped in the ASM anticyclone was considerably weaker than average in 2017 and other recent ASM seasons (including 2018)
  - Our results suggest that the relatively lightly polluted conditions in the ASM region in recent years are unlikely to be primarily attributable to systematic changes in the severity of biomass burning; the timing, strength, or location (in relation to emission sources and the anticyclone) of deep convection; or the degree of confinement of air parcels within the anticyclone
  - However, the area of the anticyclone over which pollution is distributed may play a role
  - The weaker signatures of pollution trapped in the ASM anticyclone since about 2014 likely reflect in large part the declining trend in anthropogenic CO emissions in the region