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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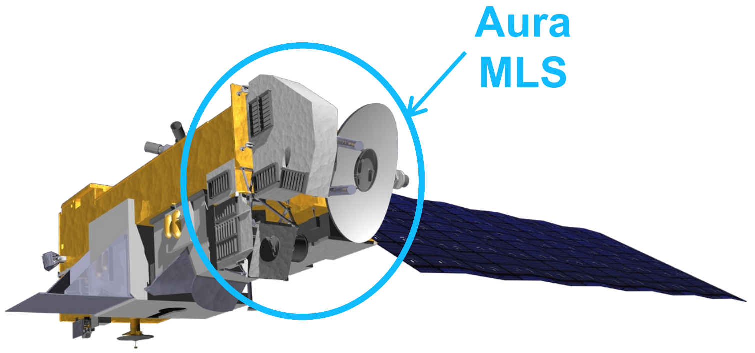
Introduction



- ✦ Satellite observations have been indispensable for analyzing the composition of the Asian summer monsoon (ASM) anticyclone, both because of its hemispheric scale and because until recently it has been sparsely sampled by other means

- ✦ Several spaceborne instruments have made important contributions to monsoon science, e.g., ACE-FTS, MIPAS, AIRS, and IASI

- ✦ Here we will focus on measurements from the **Microwave Limb Sounder (MLS)**, which was launched as part of NASA's Aura mission in July 2004

- ✦ In this talk we will:
  - ✧ Briefly introduce Aura MLS and how we apply the data to ASM studies
  - ✧ Characterize the climatological behavior of the anticyclone based on 17 years (2005–2021) of MLS measurements and MERRA-2 reanalysis fields
  - ✧ Use MLS data to place the 2017 and 2022 ASM seasons observed by the StratoClim and ACCLIP field campaigns, respectively, into the spatial and temporal context of other monsoons in the last two decades
  - ✧ Preview the 2023 ASM season now underway

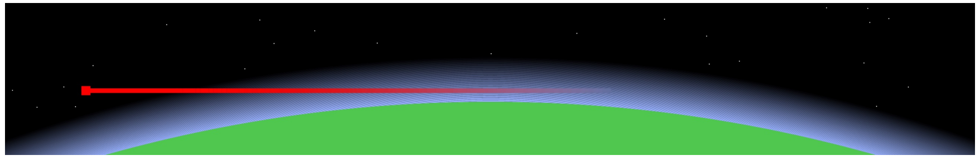
StratoClim

ACCLIP
Asian Summer Monsoon Chemical and Climate Impact Project
NSF NASA
Western Pacific 2020

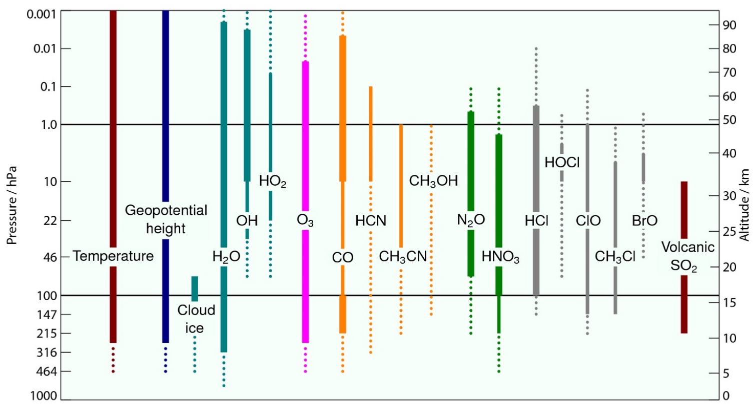
MLS data are well suited to quantifying the spatial and seasonal variations in UTLS composition

- ✦ Microwave limb sounding:
  - ✧ Passive measurements of microwave thermal emission can be made continuously day and night
  - ✧ Insensitive to aerosol and all but the thickest clouds
  - ✧ Relatively good vertical and horizontal resolution
- ✦ MLS makes daily, near-global, simultaneous measurements of several quantities relevant for monsoon studies:
  - ✧ Water vapor
  - ✧ Tropospheric tracers: **CO**, **CH_3Cl**, **CH_3CN**, CH_3OH, HCN
  - ✧ Stratospheric tracers: **O_3**, HCl, HNO_3
  - ✧ Cloud ice water content (**IWC**), an indicator of deep convection
- ✦ MLS obtains about 300 profiles each day in the general ASM region, defined here as the area enclosed within a "box" covering **10°–50°N latitude × 0°–140°E longitude**

Limb sounding

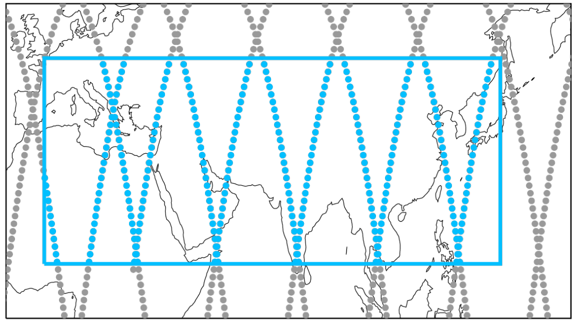


MLS version 5 measurement suite



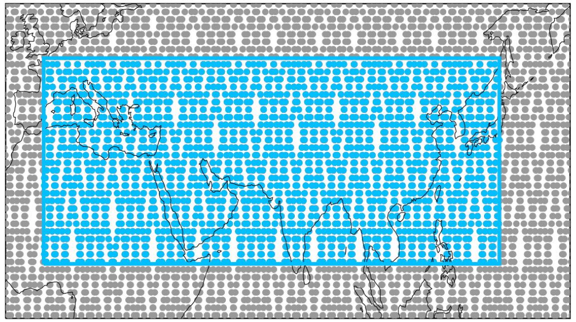
MLS Daily coverage

1 Day: 30 Jul 2017



MLS Weekly coverage

1 Week: 27 Jul -- 2 Aug 2017



✦ MLS data are interpolated to isentropic surfaces to facilitate tracking of air motions in the subtropical and extratropical upper troposphere / lower stratosphere (UTLS)

✦ For simplicity, we focus here on a single potential temperature level: **390 K**

✦ Within our ASM **box** during boreal summer (JJA), **390 K** corresponds to:

✧ Approximately 15–17 km altitude

✧ MLS retrieval pressure levels of 121–82 hPa

✦ This level lies near the core of the strong easterly jet that bounds the tropical edge of the monsoon circulation and is just above the dynamical tropopause in the subtropics

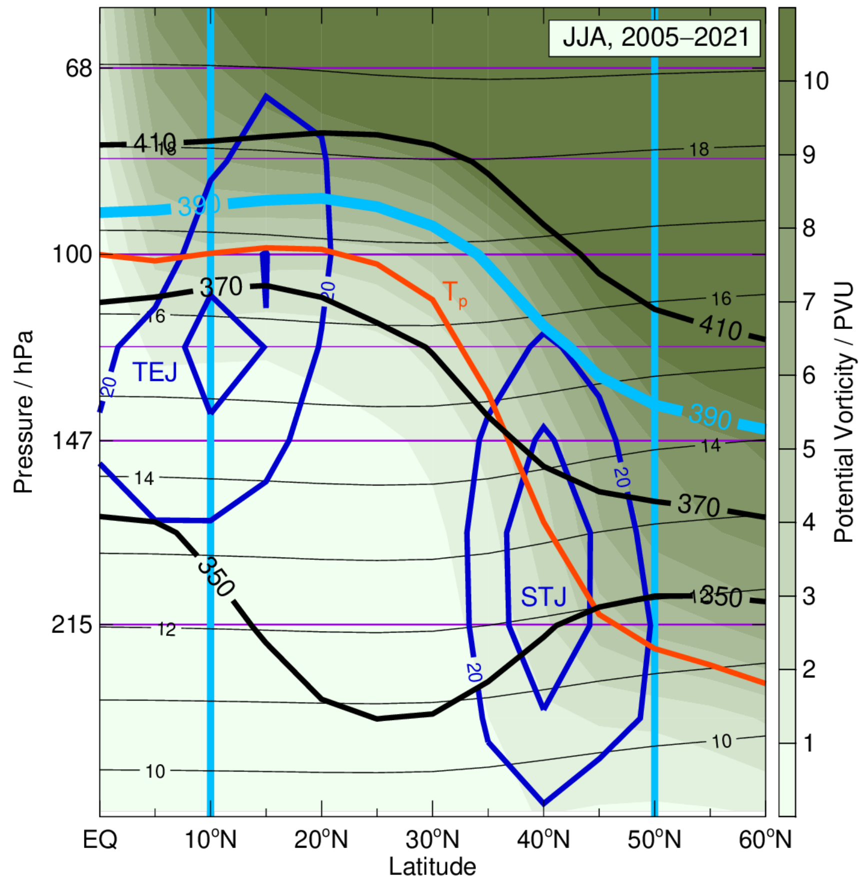
✦ We use a specified contour of **Montgomery Stream Function (MSF)** from MERRA-2 to identify the approximate "boundary" of the ASM anticyclone

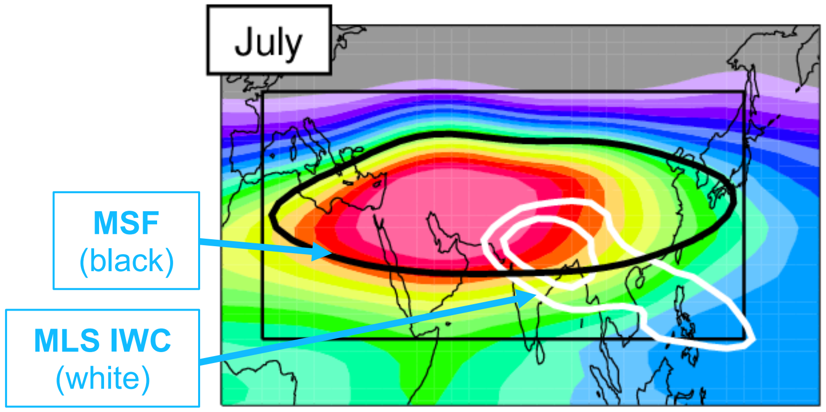
✧ MSF on isentropic surfaces plays a role analogous to that of geopotential height (GPH) on isobaric surfaces

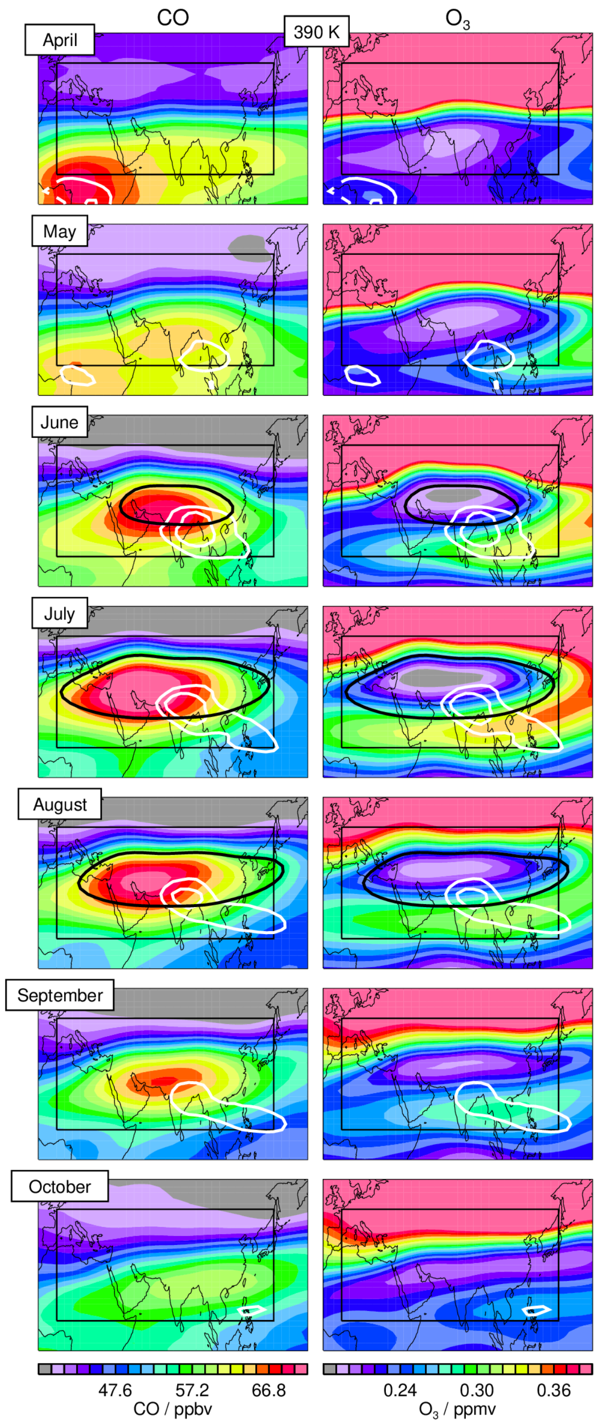
✧ A major advantage of MSF is that, unlike potential vorticity (PV), it allows a closed circulation to be defined over a wide range of isentropic levels

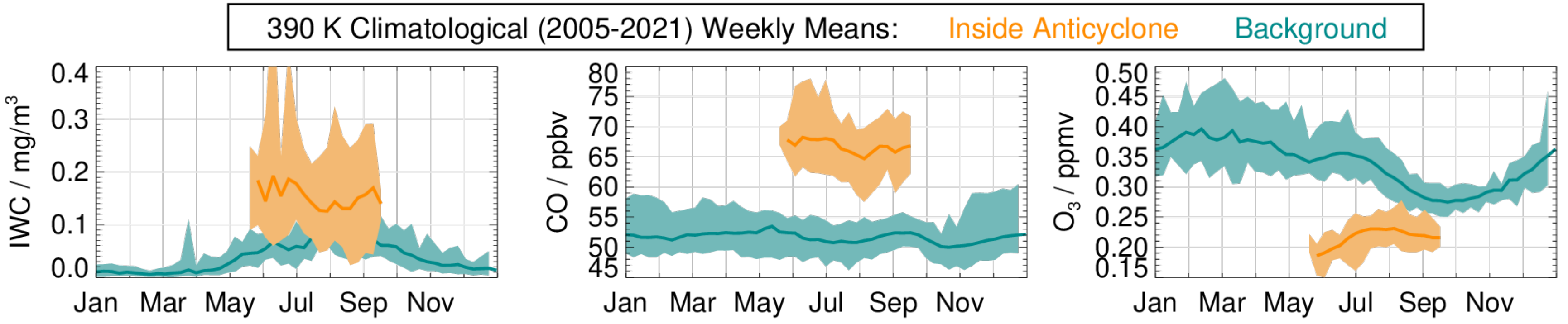
✧ Our selected MSF contour typically encloses the most substantial ASM signatures in trace gases throughout the season

✦ We use **MLS IWC** to identify regions and times of strong deep convection



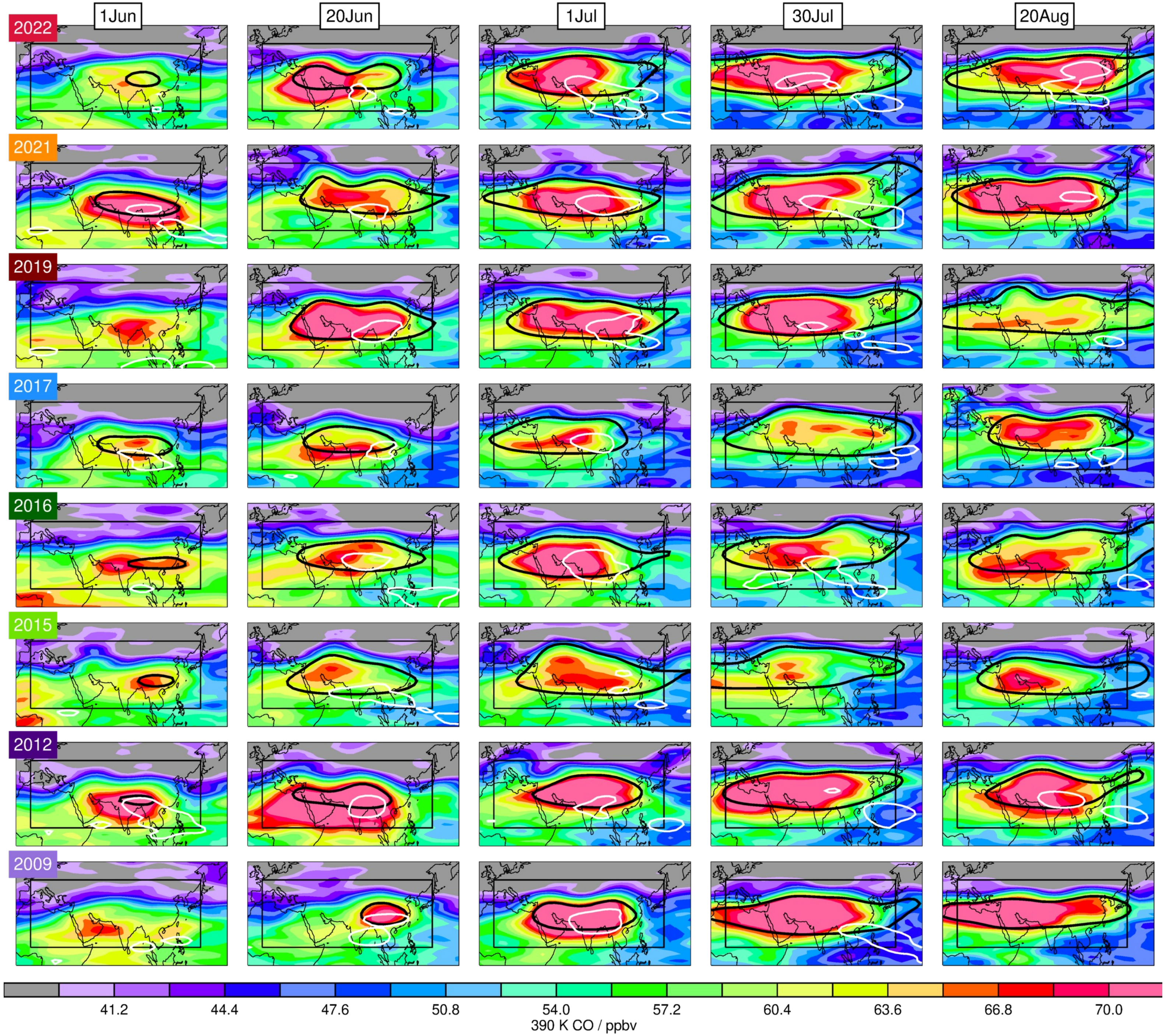






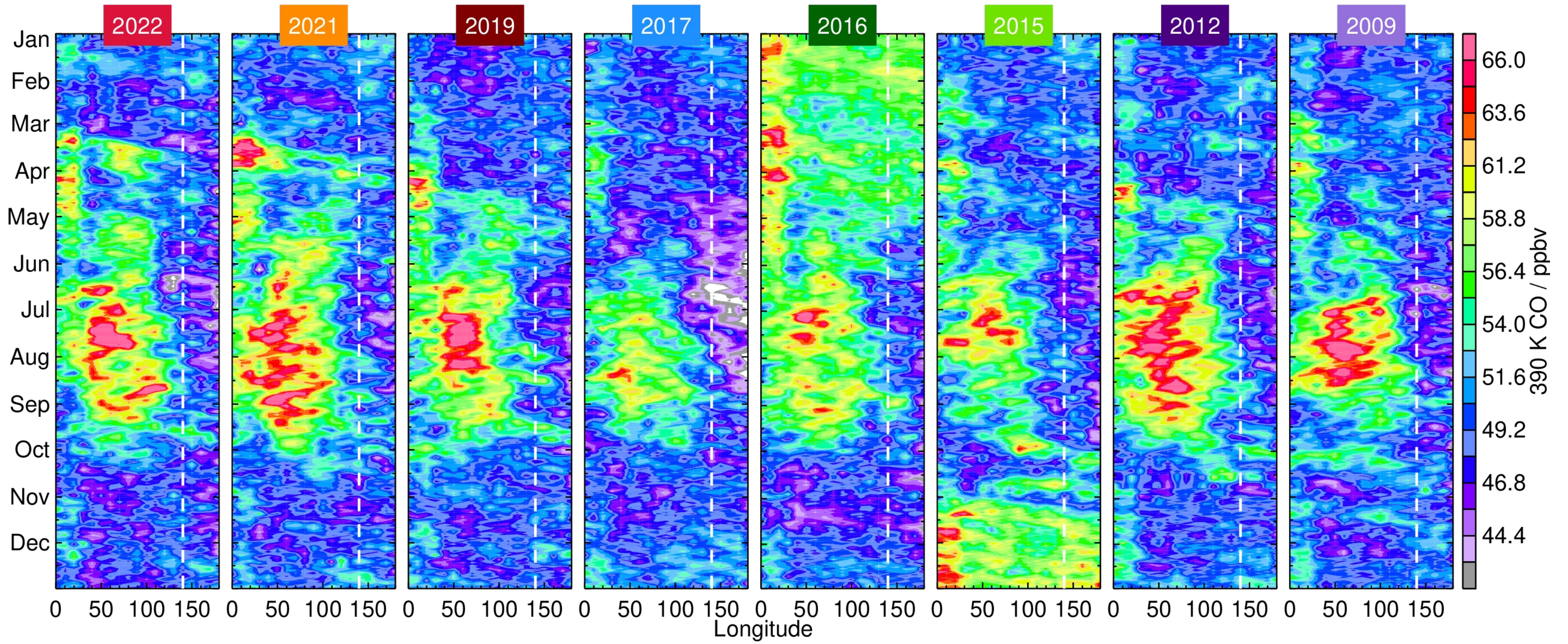
Climatological (2005–2021) picture:

- ✦ April: background state
- ✦ May: ASM onset phase
  - ✧ Direct injection of surface pollutants into the UTLS via deep convection is starting to occur
  - ✧ Although the climatological monthly mean anticyclonic circulation is still weak, CO is already slightly enhanced over a sizeable portion of the ASM study box
- ✦ June-July-August: ASM mature phase
  - ✧ Intense deep convection over a broad region, generally to the southeast of the anticyclone core
  - ✧ CO shows a strong signature of surface emissions convectively lifted and trapped in anticyclone
  - ✧ Lofting of ozone-poor near-surface air reduces ozone inside the anticyclone
  - ✧ In-mixing – horizontal advection of midlatitude stratospheric air around the eastern flank of the anticyclone and into the tropical uppermost troposphere – increases low-latitude ozone
- ✦ September-October: ASM retreat phase
  - ✧ Deep convection dies down, the anticyclone dissipates, and in-mixing wanes
  - ✧ Monsoonal signatures in UTLS composition fade, with only small effects still seen in October



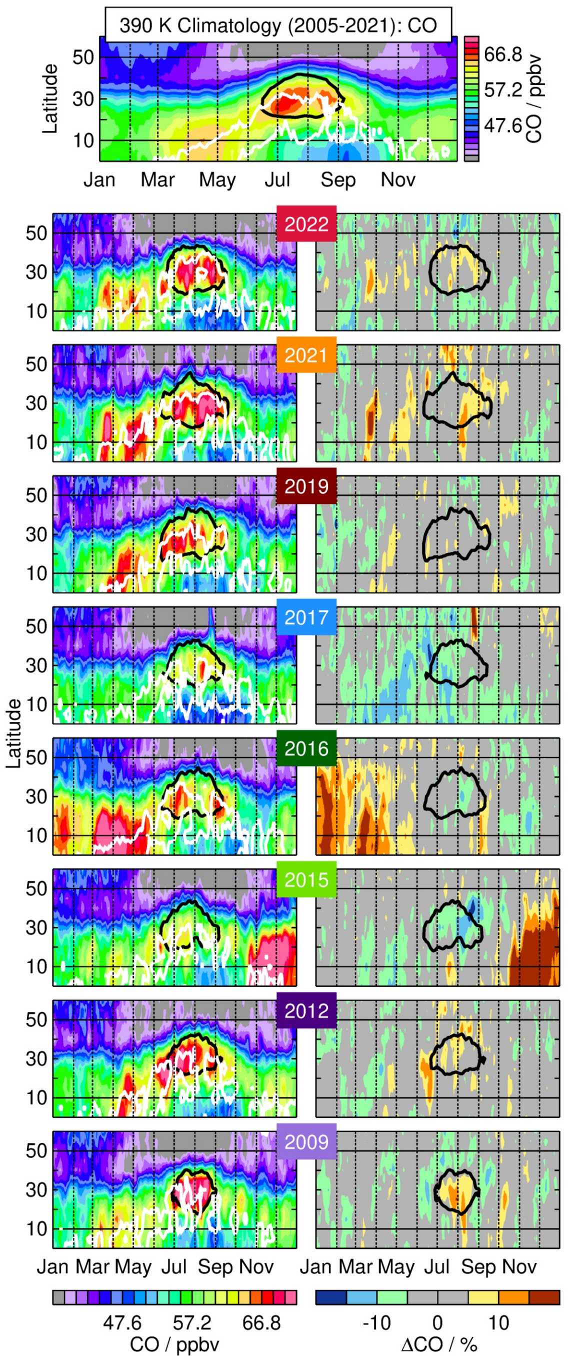
Weekly mean maps of MLS CO illustrate seasonal and interannual variability

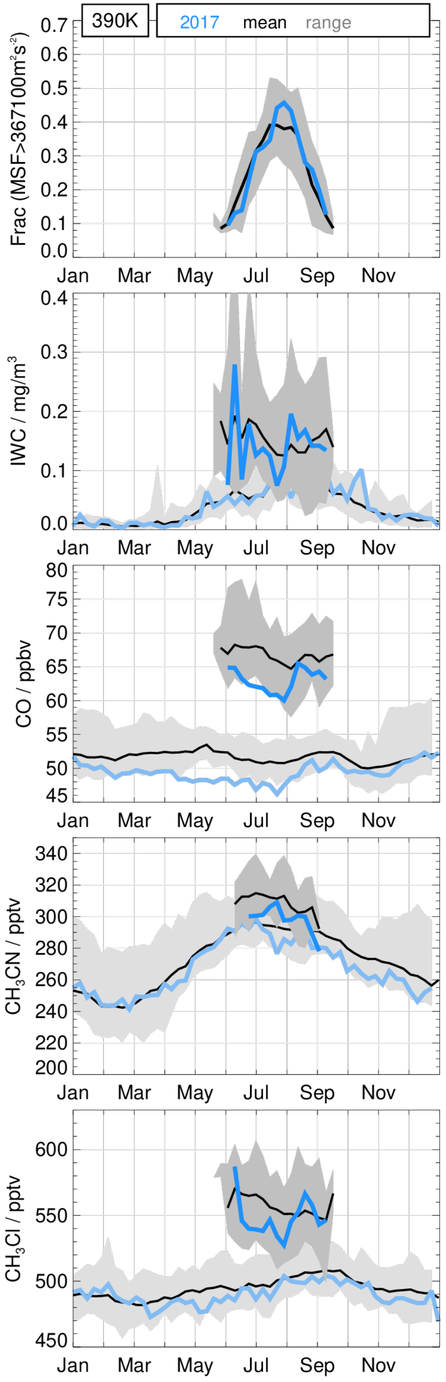
- ✦ Rows → snapshots of the seasonal evolution of the anticyclone in a given year
- ✦ Columns → interannual variability on a given date
- ✦ The ASM anticyclone exhibits substantial variability in the timing, the magnitude, and the location of extreme values, both intraseasonally and interannually
- ✦ Interpretation of the interannual variability is complicated by the strong intraseasonal variability



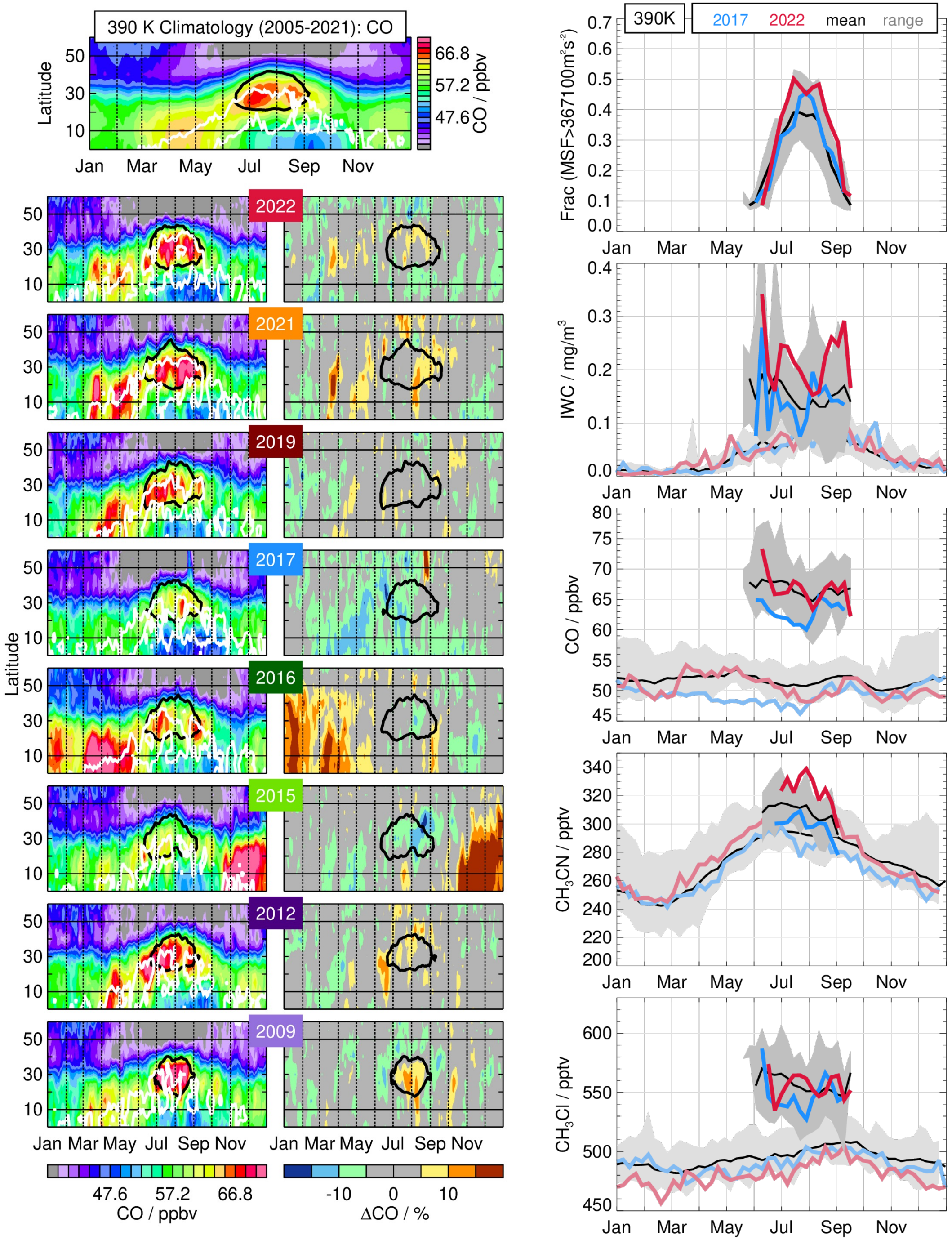
The value of a long record: Overview of the year-to-year variability in CO in the ASM region observed by MLS at 390 K

- ✦ Strong CO enhancements in the ASM region in **2009** and **2012** (and other years early in the Aura mission, not shown)
- ✦ Substantial perturbations to the broad UTLS CO distribution in late **2015** / early **2016** arising from the severe fires in Indonesia associated with the extreme El Niño at that time, but with relatively low CO inside the anticyclone during those ASM seasons
- ✦ A generally weaker signature of pollution in the ASM region from 2014 to 2018, particularly in **2017**, when the StratoClim campaign took place
- ✦ A return to strongly polluted conditions in the region during the most recent ASM seasons, including **2019**, **2021**, and **2022**, when the ACCLIP campaign took place





- ✦ **Anticyclone area** (fraction of MLS points inside our MSF contour)
  - ✧ **2017:** slightly larger than average in July, otherwise fairly typical
- ✦ **Deep convection** (MLS IWC)
  - ✧ **2017:** slightly weaker than typical in July, intensified in early August
- ✦ **Background CO abundances**
  - ✧ **2017:** ~5–10% below average, well outside MLS mission envelope; strong, extensive, persistent negative CO anomaly unique in record
- ✦ **Inside-anticyclone CO abundances**
  - ✧ **2017:** ~10% smaller than typical until August; rose steeply with IWC
- ✦ **CH_3CN** (produced almost exclusively by biomass burning)
  - ✧ **2017:** roughly climatological background values prior to the ASM season, but persistently slightly low values inside the anticyclone
- ✦ **CH_3Cl** (mainly biogenic, biomass/biofuel burning; industrial sources)
  - ✧ **2017:** also fairly low values in anticyclone until mid-August



✦ **Anticyclone area** (fraction of MLS points inside our MSF contour)

- ✧ **2017:** slightly larger than average in July, otherwise fairly typical
- ✧ **2022:** among the largest seen by MLS for much of the ASM season

✦ **Deep convection** (MLS IWC)

- ✧ **2017:** slightly weaker than typical in July, intensified in early August
- ✧ **2022:** relatively strong throughout the ASM season

✦ **Background CO abundances**

- ✧ **2017:** ~5–10% below average, well outside MLS mission envelope; strong, extensive, persistent negative CO anomaly unique in record
- ✧ **2022:** mostly close to average, though a bit low in July and August

✦ **Inside-anticyclone CO abundances**

- ✧ **2017:** ~10% smaller than typical until August; rose steeply with IWC
- ✧ **2022:** near average through most of the season, especially August

✦ **CH_3CN** (produced almost exclusively by biomass burning)

- ✧ **2017:** roughly climatological background values prior to the ASM season, but persistently slightly low values inside the anticyclone
- ✧ **2022:** very high (envelope-redefining) values inside the anticyclone

✦ **CH_3Cl** (mainly biogenic, biomass/biofuel burning; industrial sources)

- ✧ **2017:** also fairly low values in anticyclone until mid-August
- ✧ **2022:** low anticyclone values in June, but near-average thereafter

Summary and a quick look at the developing 2023 ASM anticyclone

- ✦ Aura MLS measures several quantities relevant for monsoon studies, including species of both tropospheric (e.g., CO, CH_3Cl, CH_3CN, CH_3OH, HCN) and stratospheric (O_3, HNO_3, HCl) origin, as well as cloud ice water content (IWC, a proxy for deep convection)
- ✦ We examined 18 years of MLS data to characterize the climatological composition of the ASM anticyclone and investigate intraseasonal and interannual variability in the UTLS response to the monsoon
- ✦ Satellite measurements lack the fine spatial resolution of airborne in situ data, but the MLS multi-year record with daily global coverage provides valuable spatial and temporal context for field campaigns
- ✦ MLS data indicate that the amount of pollution trapped inside the anticyclone was unusually low in 2017 during StratoClim, whereas it was about average in 2022 during ACCLIP
- ✦ The 2023 ASM season is now underway
  - ✧ The anticyclone – which is just beginning to develop – is slightly larger than it was at this point in the season in 2022
  - ✧ A strong signature of pollution trapped in the anticyclone is not yet apparent