Impacts of the Asian summer monsoon on UTLS composition: Observations and Modeling

Dr. Ren Smith

Atmospheric Chemistry Observations & Modeling Lab

NSF National Center for Atmospheric Research

wsmith@ucar.edu

SAGE III Science Team Meeting

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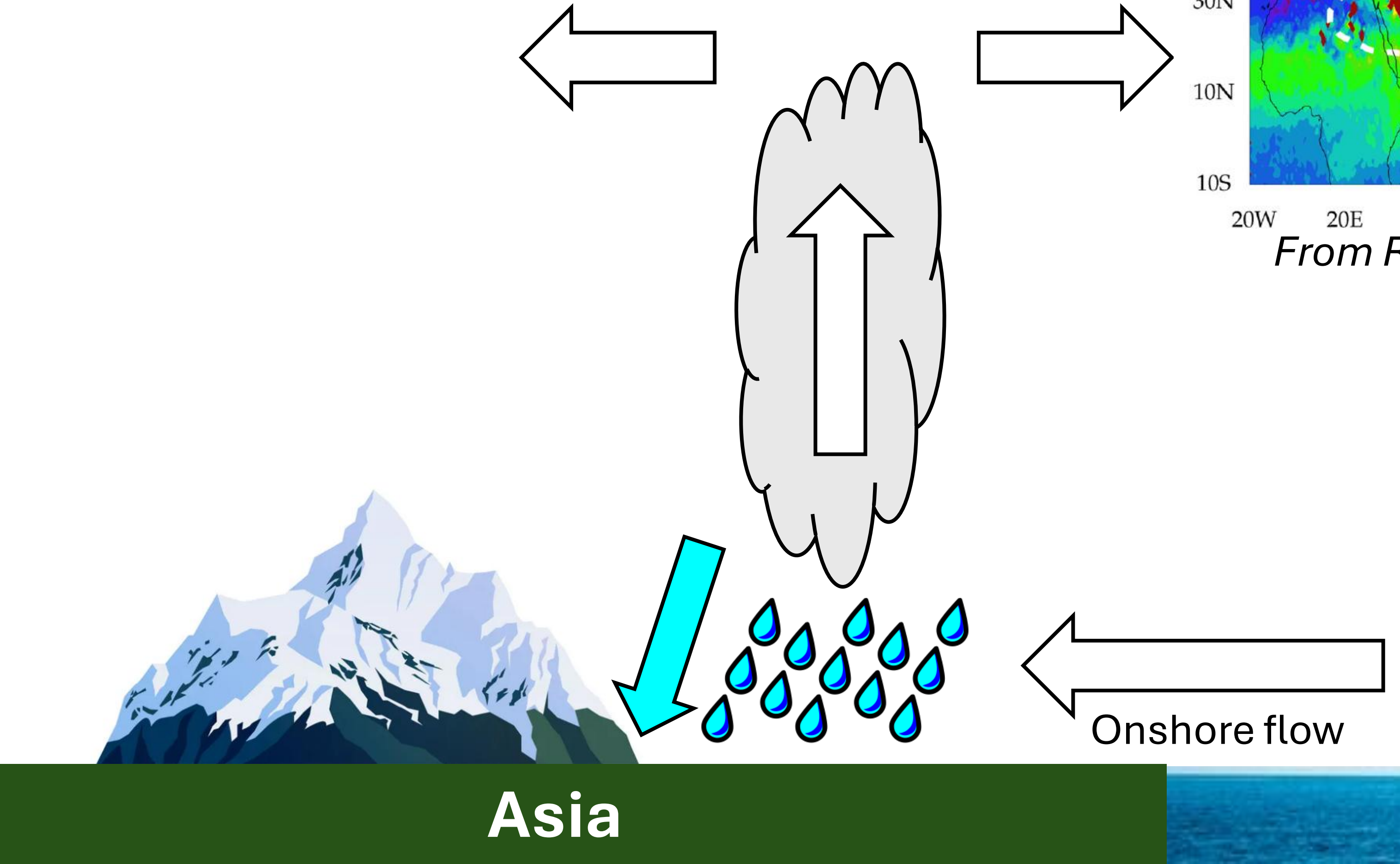
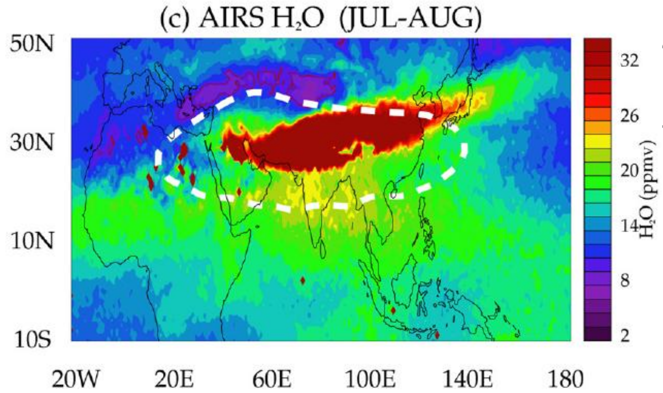
Thanks to support from:

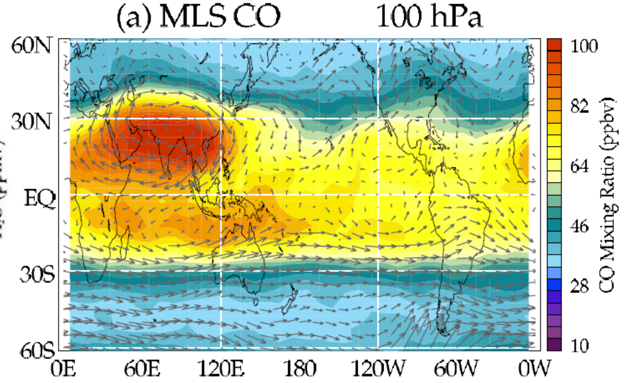
Laura Pan, Rei Ueyama, Simone Tilmes, the ACCLIP science team, the NCAR multi-scale modeling team, and many more!

Recent research has focused on what *rises* through the ASM, rather than what *falls*

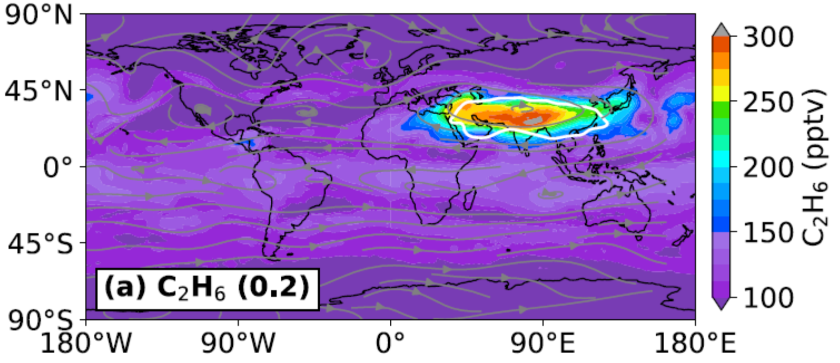




From Randel et al. (2006)

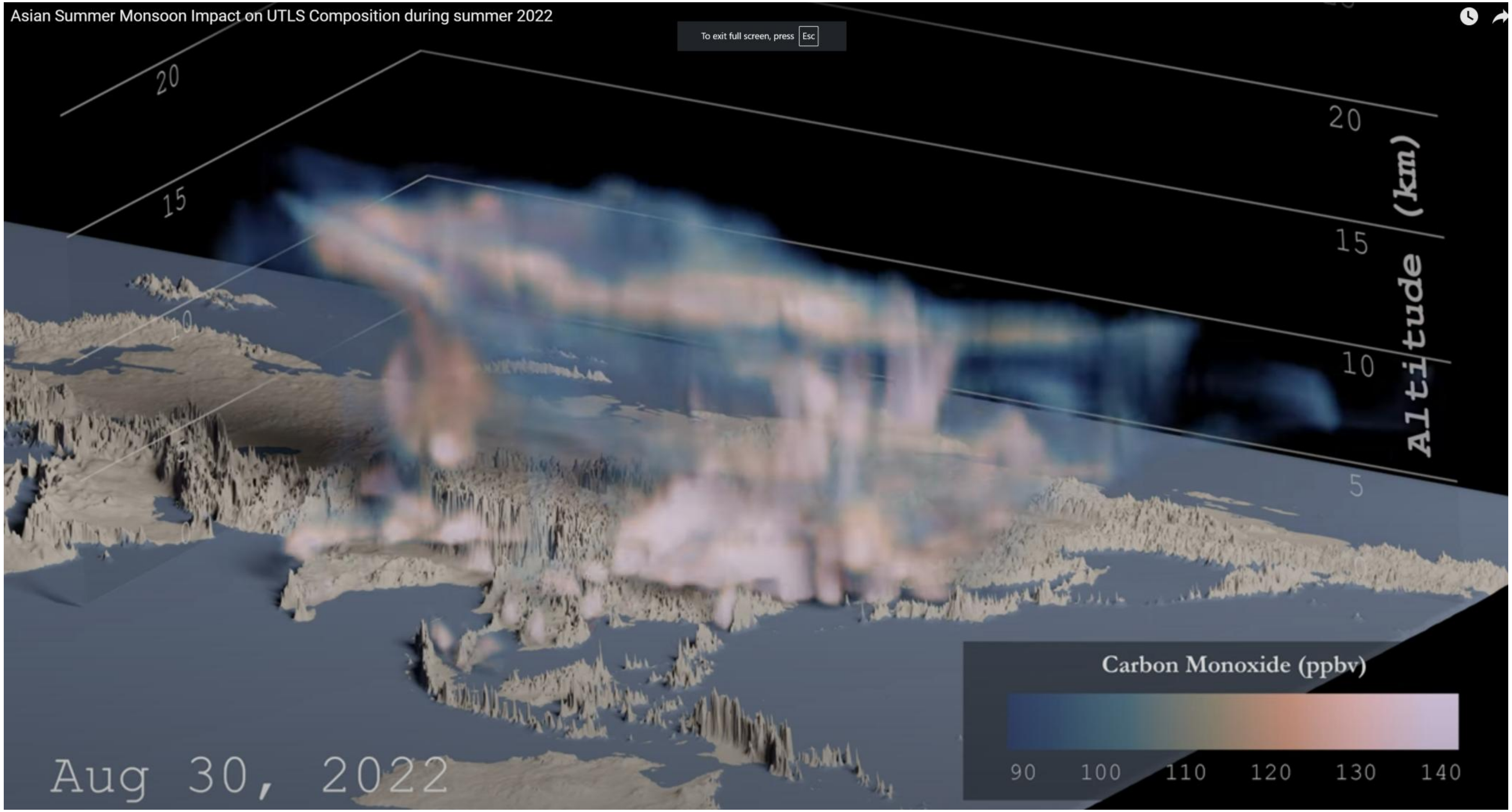


From Park et al. (2009)

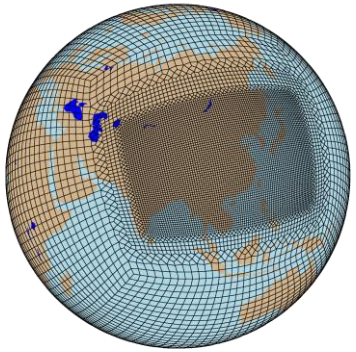


From Smith et al. (2024)

Asian summer monsoon (ASM) deep convection exports pollution to the global atmosphere

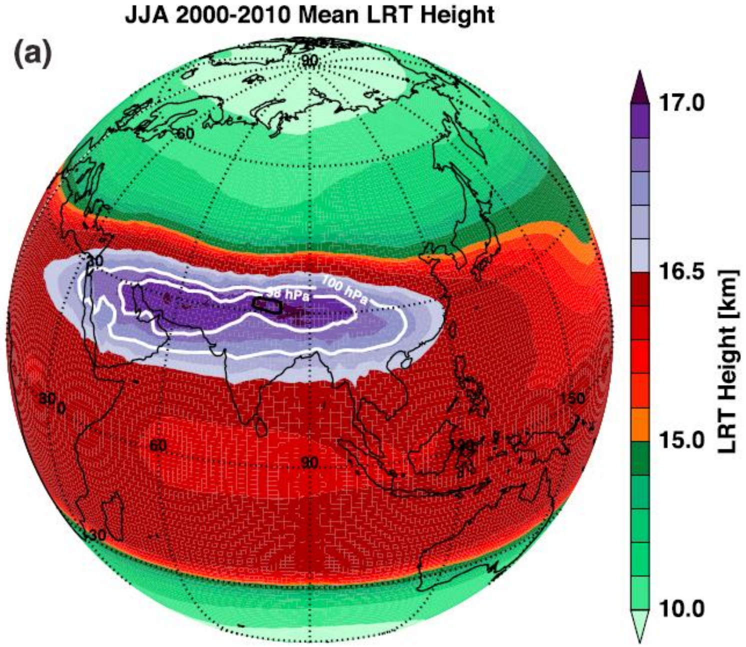


Link to animation

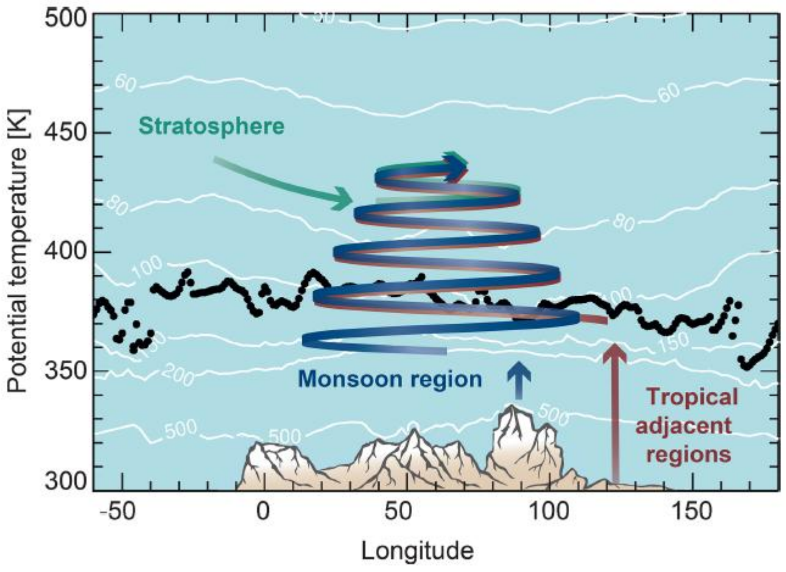


MUSICA CO rendering by Matt Rehme, NSF NCAR/CISL

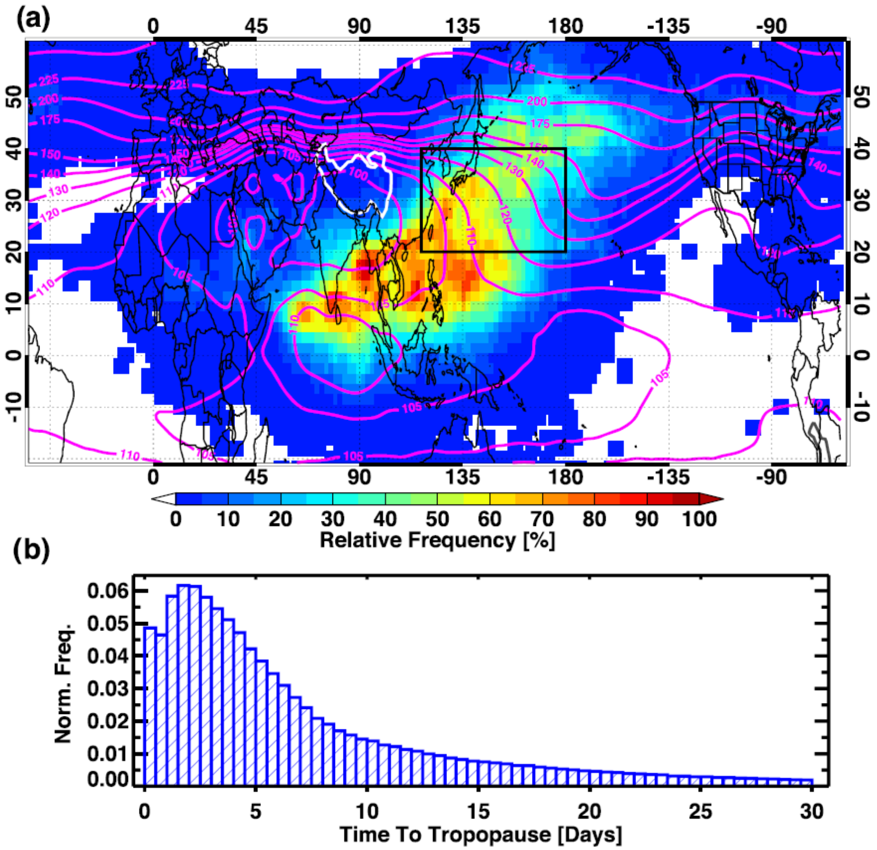
Pollutants lofted by ASM convection have a pathway to enter the stratosphere



Pan et al. (2016)



Vogel et al. (2019)



Honomichl and Pan (2020)

Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

Principal Investigators: Laura Pan (NCAR), Paul Newman (NASA)
Lead Co-Investigators: Elliot Atlas (Univ. Miami), William Randel (NCAR), Troy Thornberry (NOAA), Brian Toon (CU)

Primary Goal: To investigate the impacts of Asian gas and aerosol emissions on global chemistry and climate via the linkage of Asian Summer Monsoon (ASM) convection and associated large-scale dynamics

Scientific Objectives: Obtain a comprehensive suite of dynamical, chemical and microphysical measurements in the region of ASM anticyclone to address:

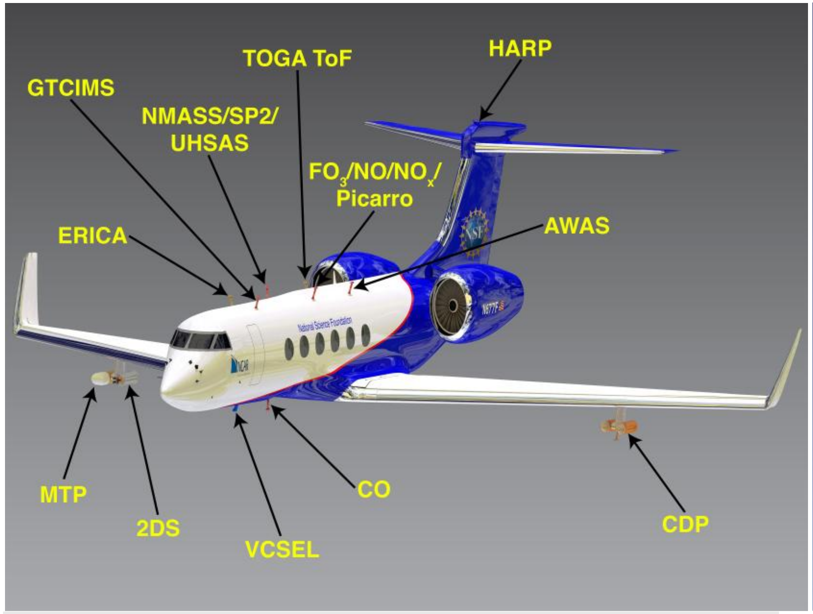
1) the **transport pathways** (vertical range, intensity, and time-scale) of the ASM uplifted air from inside of the anticyclone to the global upper troposphere and lower stratosphere (UTLS)
2) the **chemical content** of air processed in the ASM for UTLS ozone chemistry, and short-lived climate forcers
3) the information on **aerosol** size, mass and chemical composition for determining the radiative impact
4) the **water vapor** distribution associated with the monsoon dynamical structure

Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

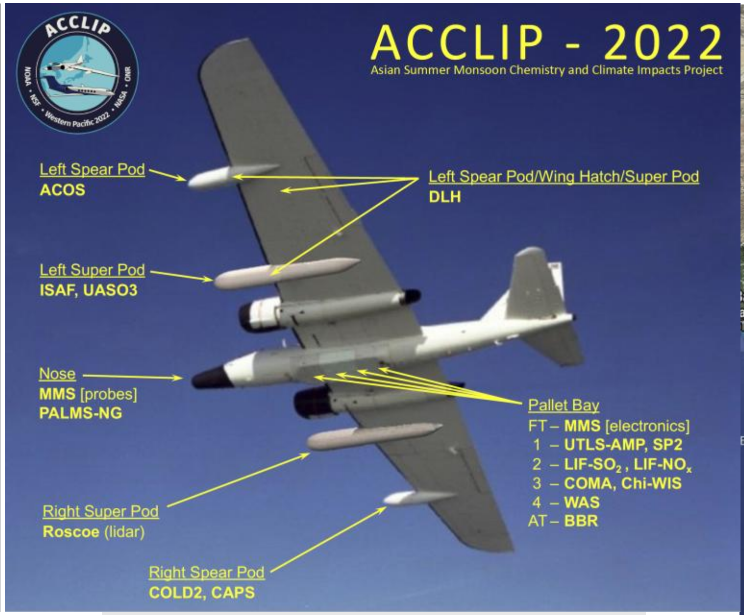
ACCLIP team members at Osan Air Base, Republic of Korea, July – September 2022

Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

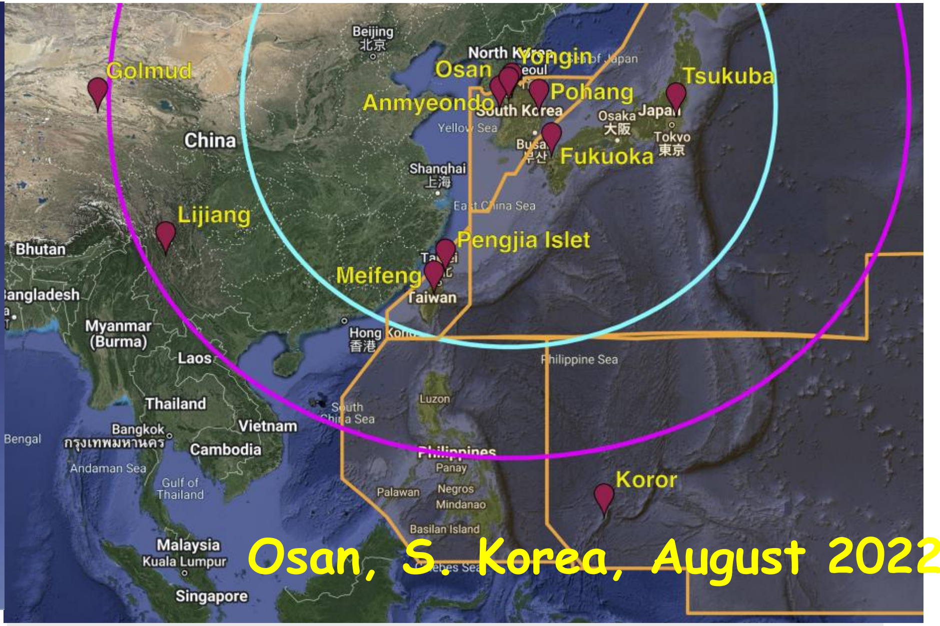
Principal Investigators: Laura Pan (NCAR), Paul Newman (NASA)
Lead Co-Investigators: Elliot Atlas (Univ. Miami), William Randel (NCAR), Troy Thornberry (NOAA), Brian Toon (CU)



NSF/NCAR Gulfstream V (GV)
Duration: ~ 8 hr flight
500 ft (0.2 km) and FL 470 (14.7 km)
(~51 kft ,15.4 km GPS altitude during ACCLIP)



NASA WB-57
Duration: ~ 6 hr
FL 430 (13 km) and FL 620 (19 km)

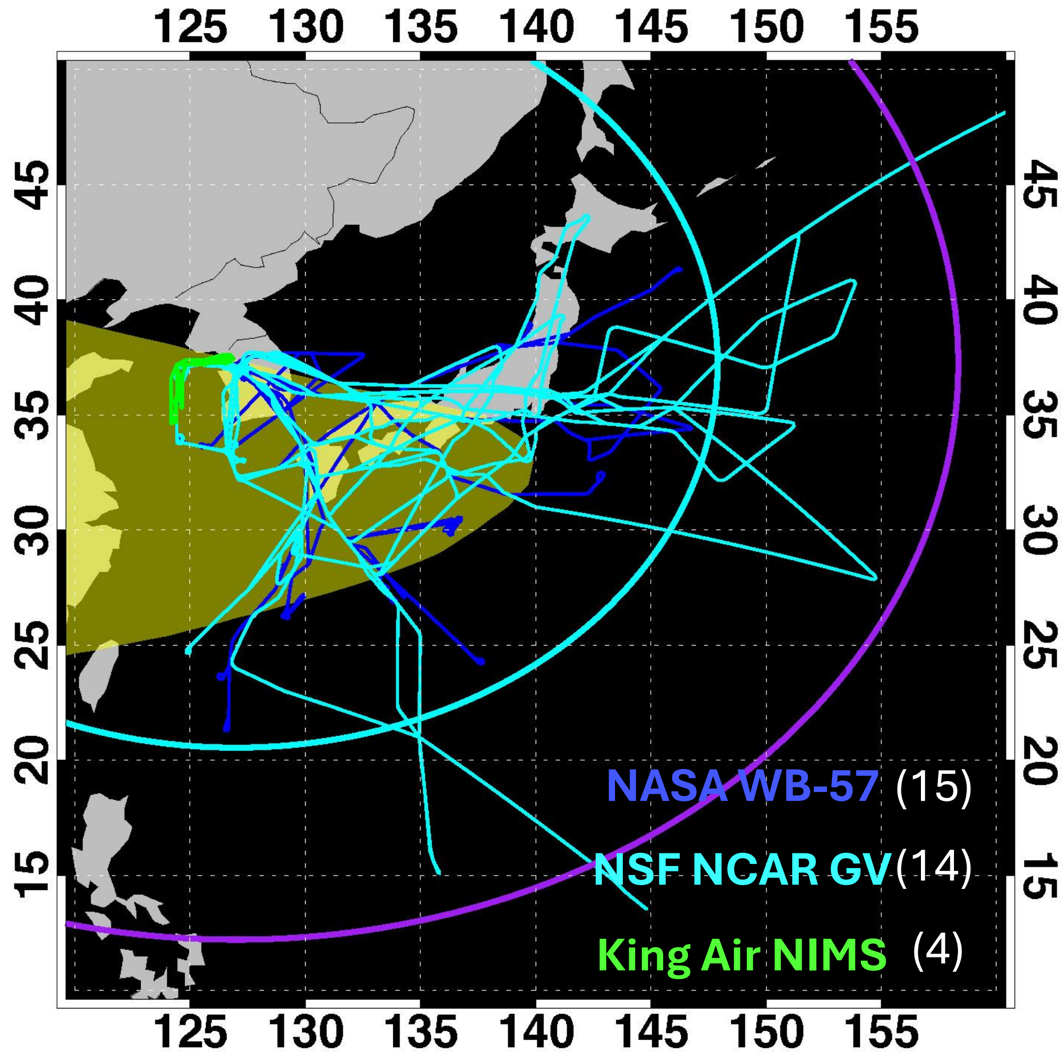


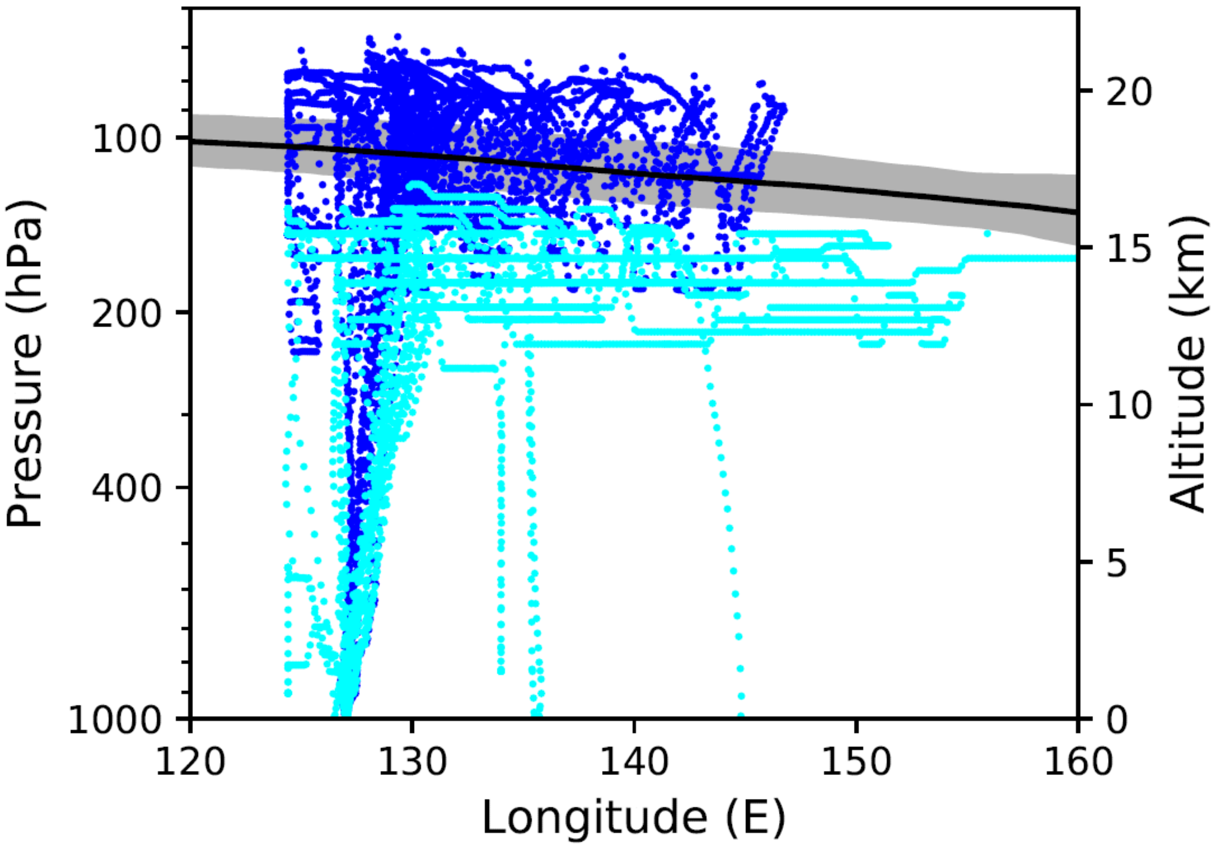
Ground Based Soundings

Sensors:
Ozonesondes, CFH, Particle soundings, Ground-based lidar, Whole air samples

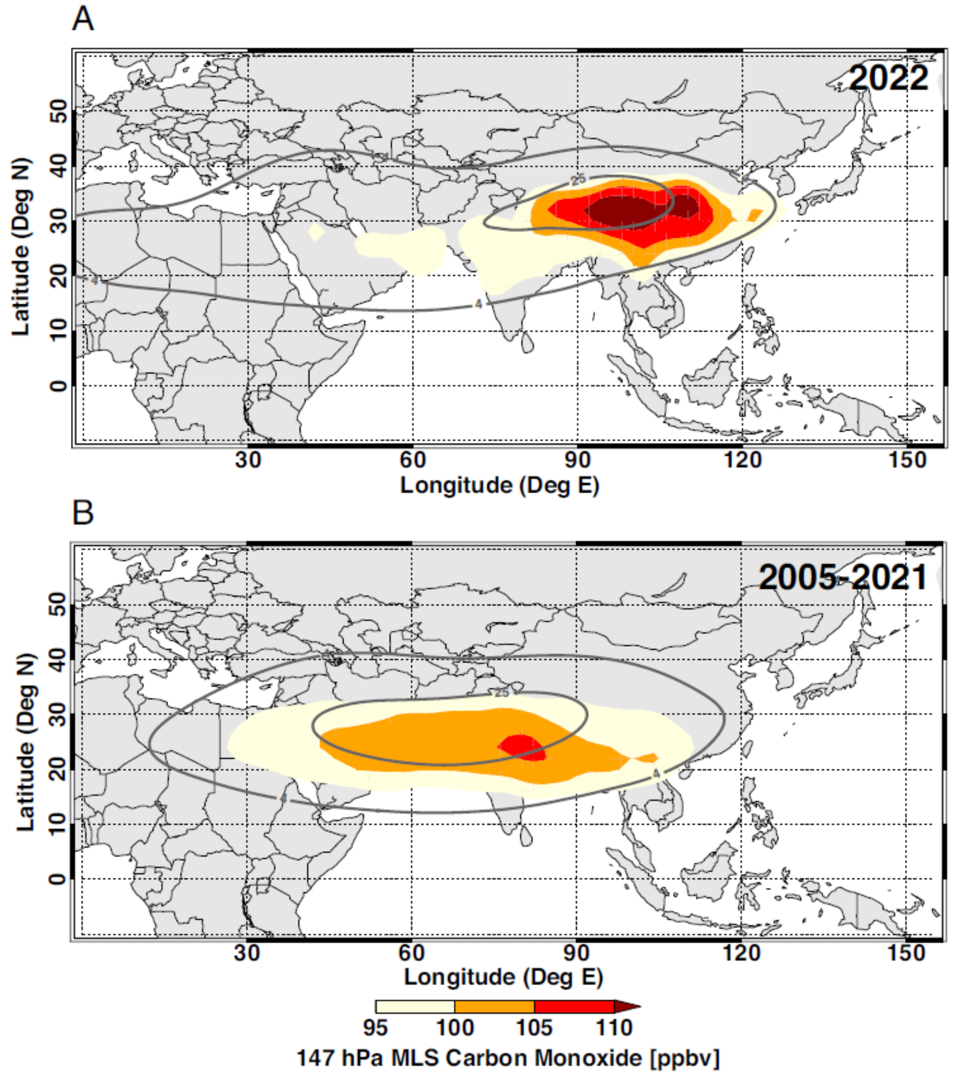
***Participated by*:**
US: NSF/CU; **Korea:** Multiple universities & NIER
Japan: Universities and NIES; **China:** CAS/IAP
Taiwan & UK: Academia Sinica & University of East Anglia
Germany: AWI

Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

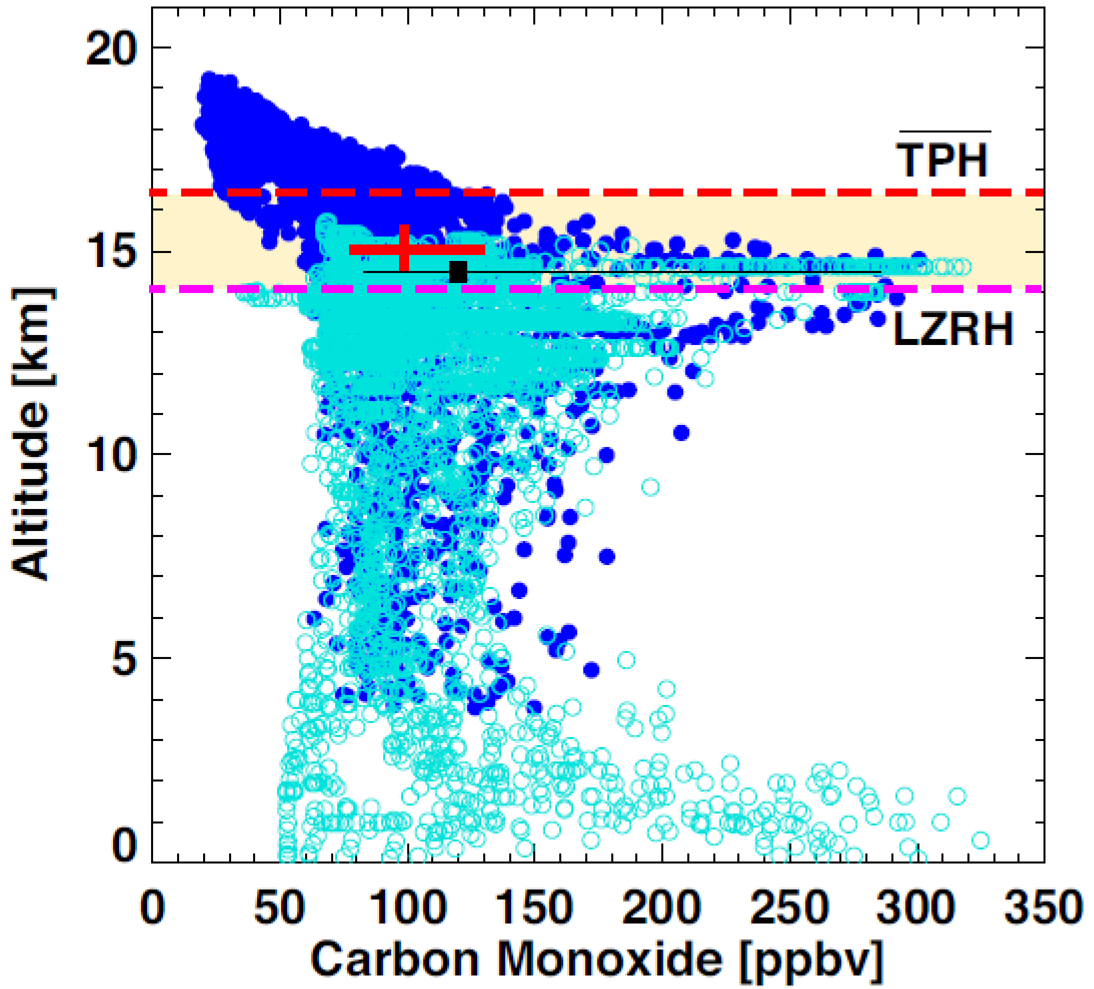




ACCLIP sampled unprecedented pollution mixing ratios in the UTLS

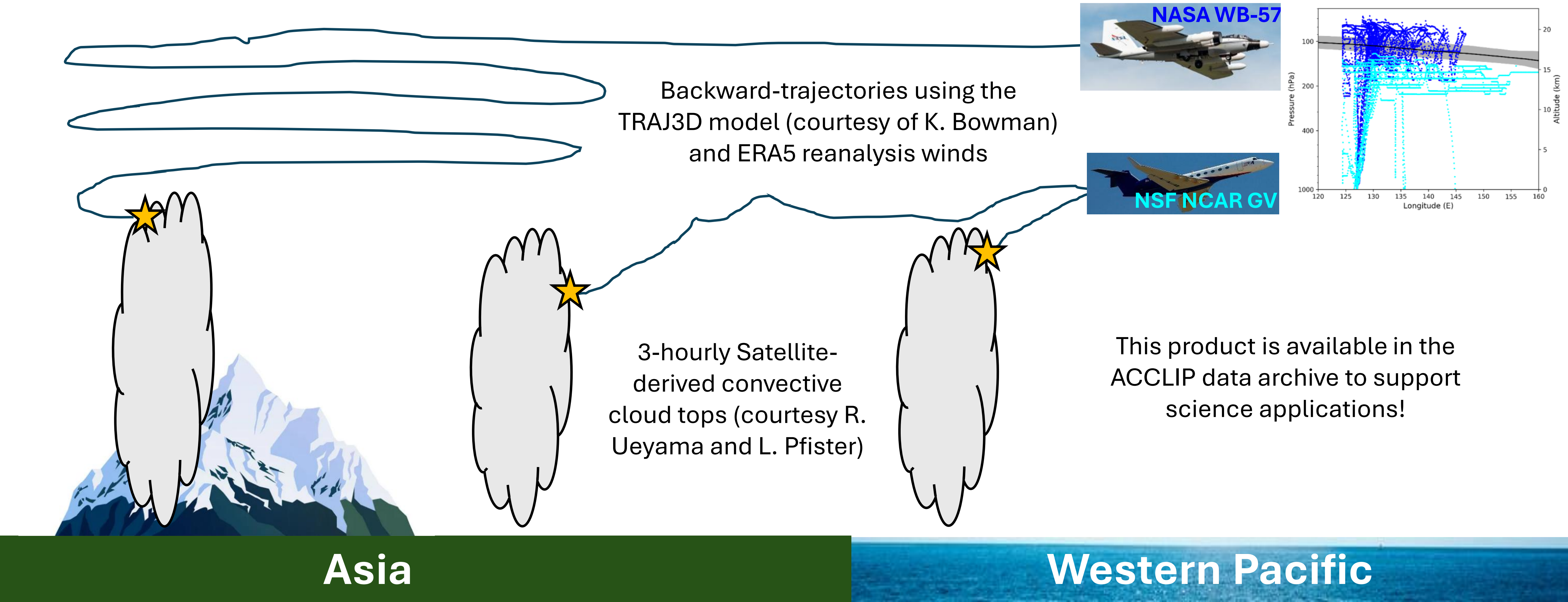


Figures courtesy of Pan et al. (2024)

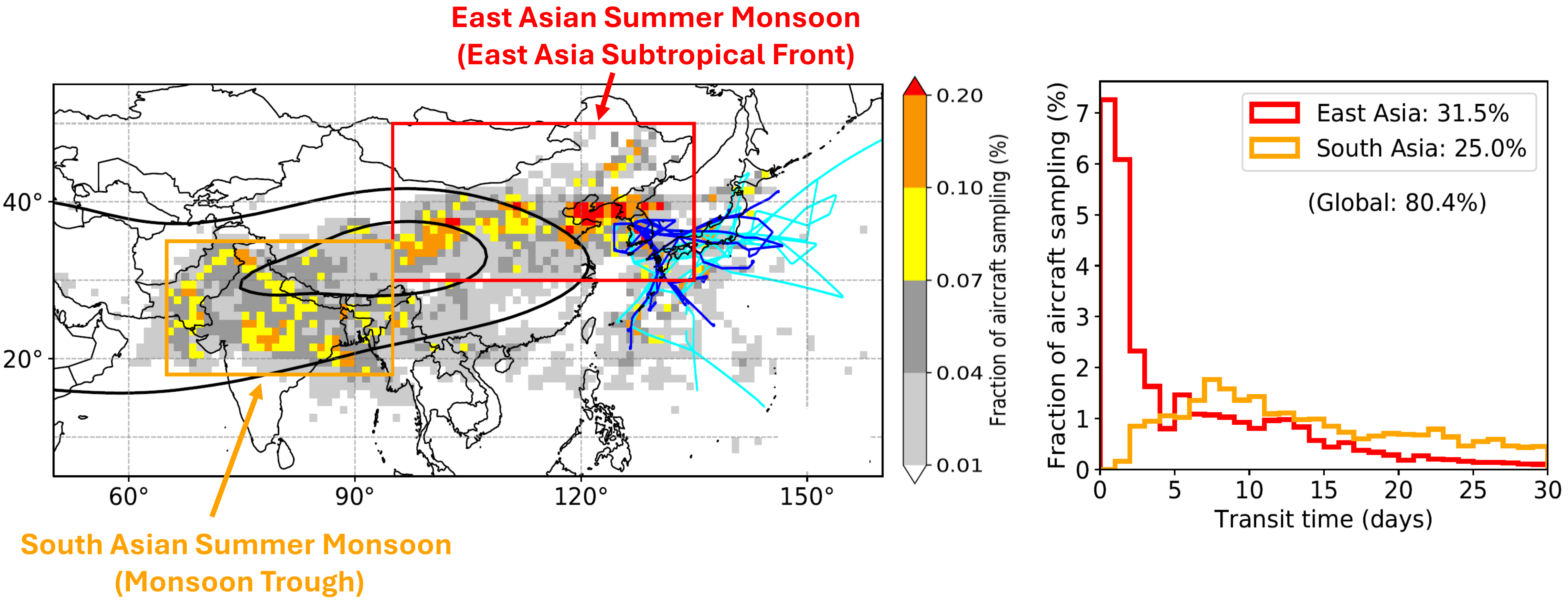


GV CO data provided by T. Campos, WB-57 CO data provided by S. Viciani and the COLD2 instrument team

Where and when were ASM convective contributions to ACCLIP airborne sampling?

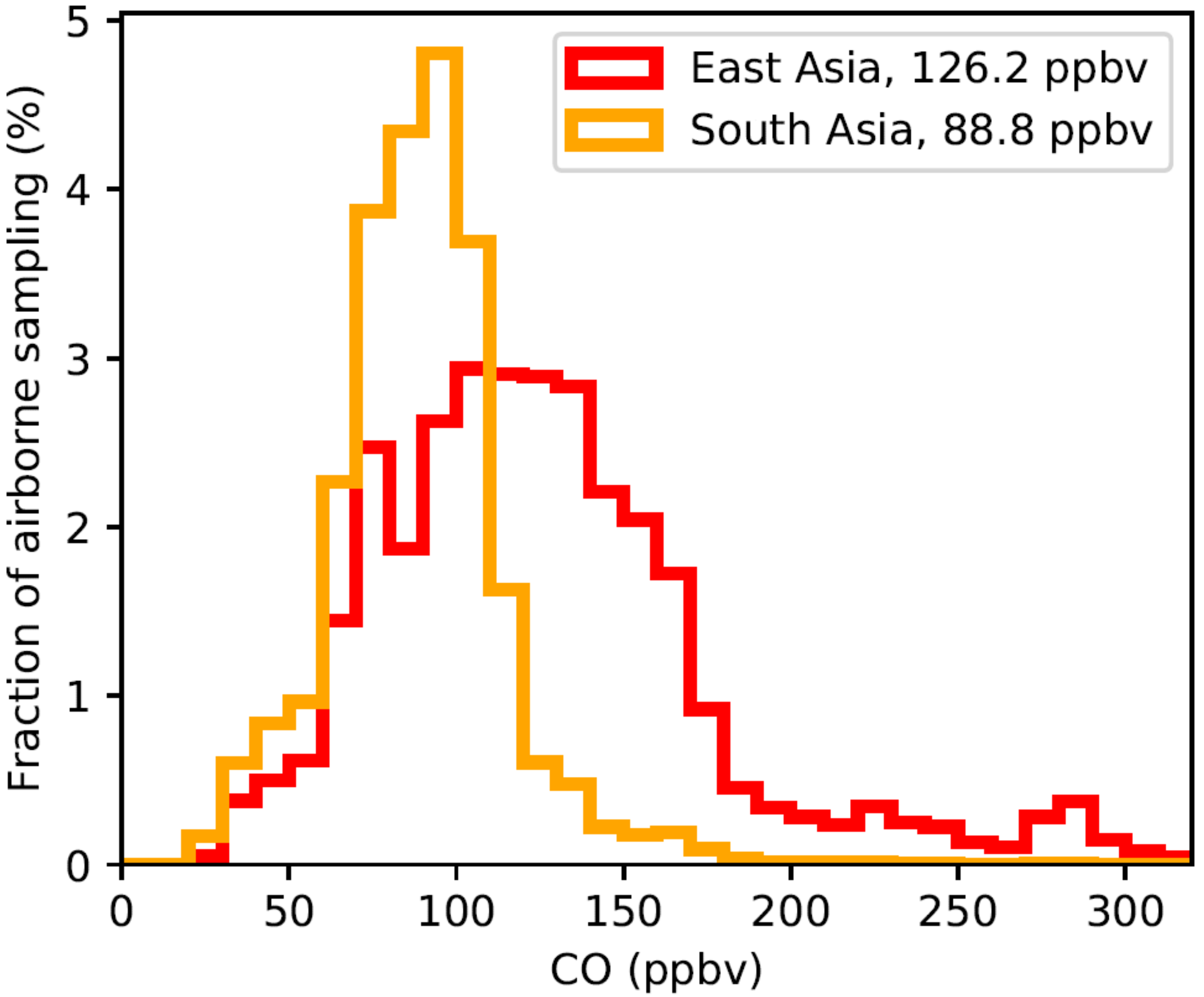


ACCLIP sampled convective outflow from two ASM sub-systems

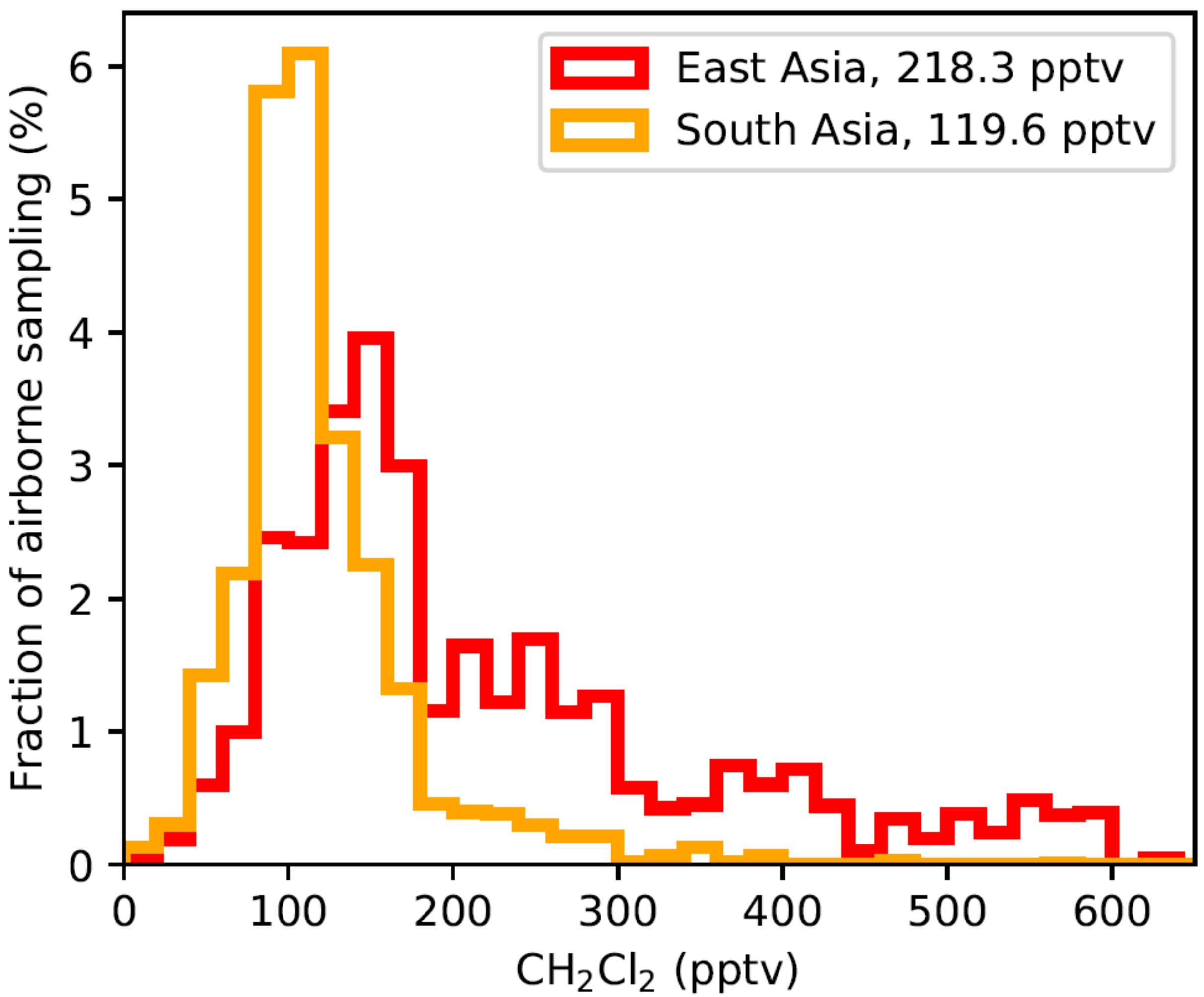


Smith et al. (2025, in review at JGR-Atm)

Convective outflow from along the EASF was generally more polluted than South Asia outflow

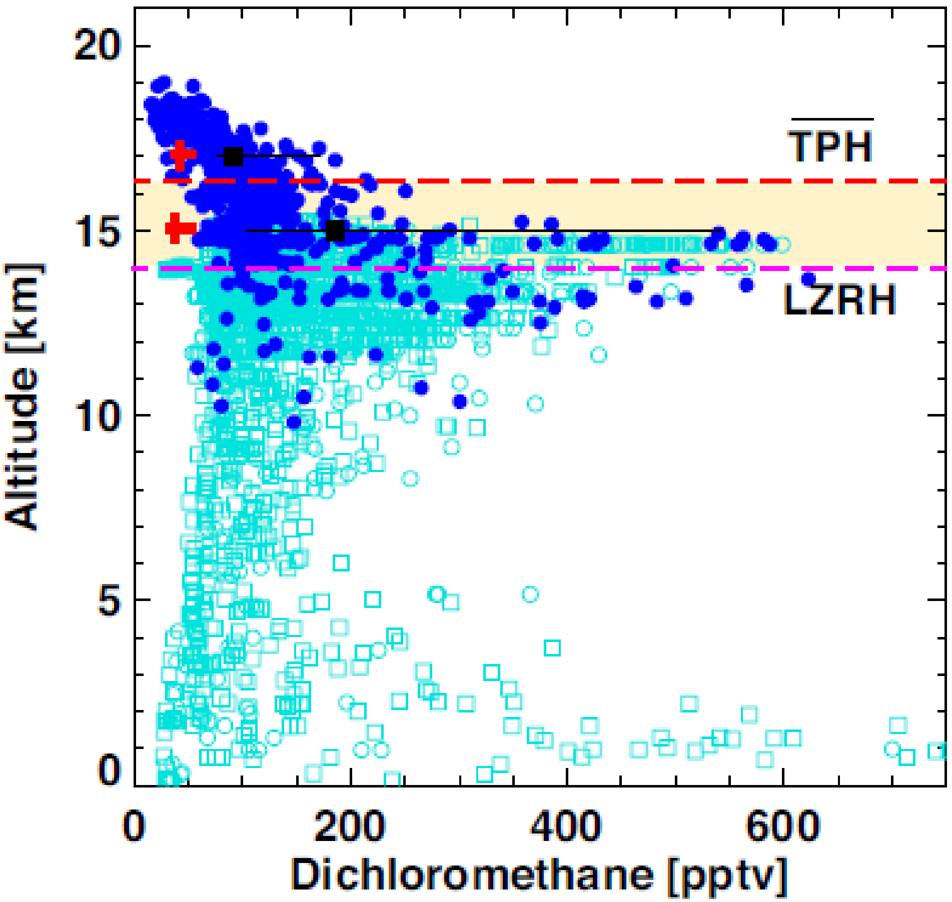


GV CO data provided by T. Campos, WB-57 CO data provided by S. Viciani and the COLD2 instrument team

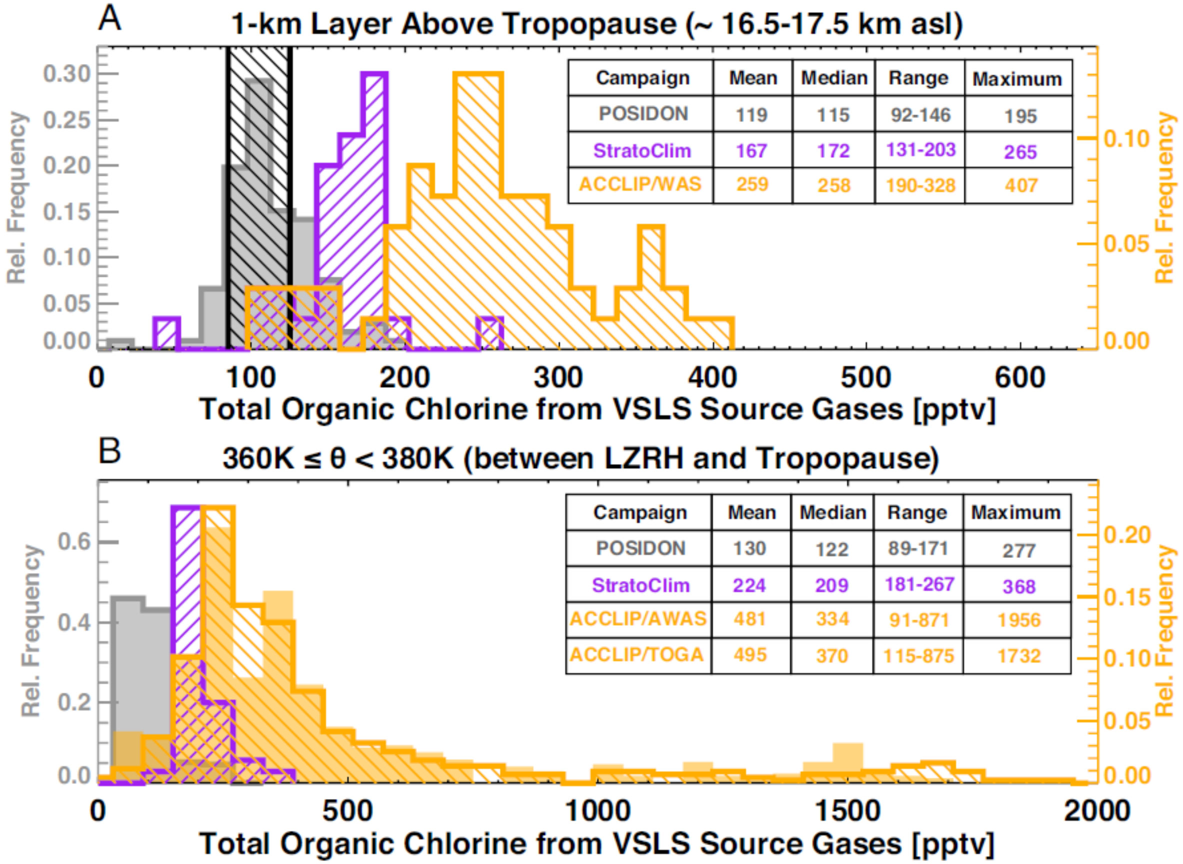


Dichloromethane observations on both aircraft courtesy of E. Atlas and the WAS team

The ASM lofts short-lived chlorine to the stratosphere, in excess of current estimates

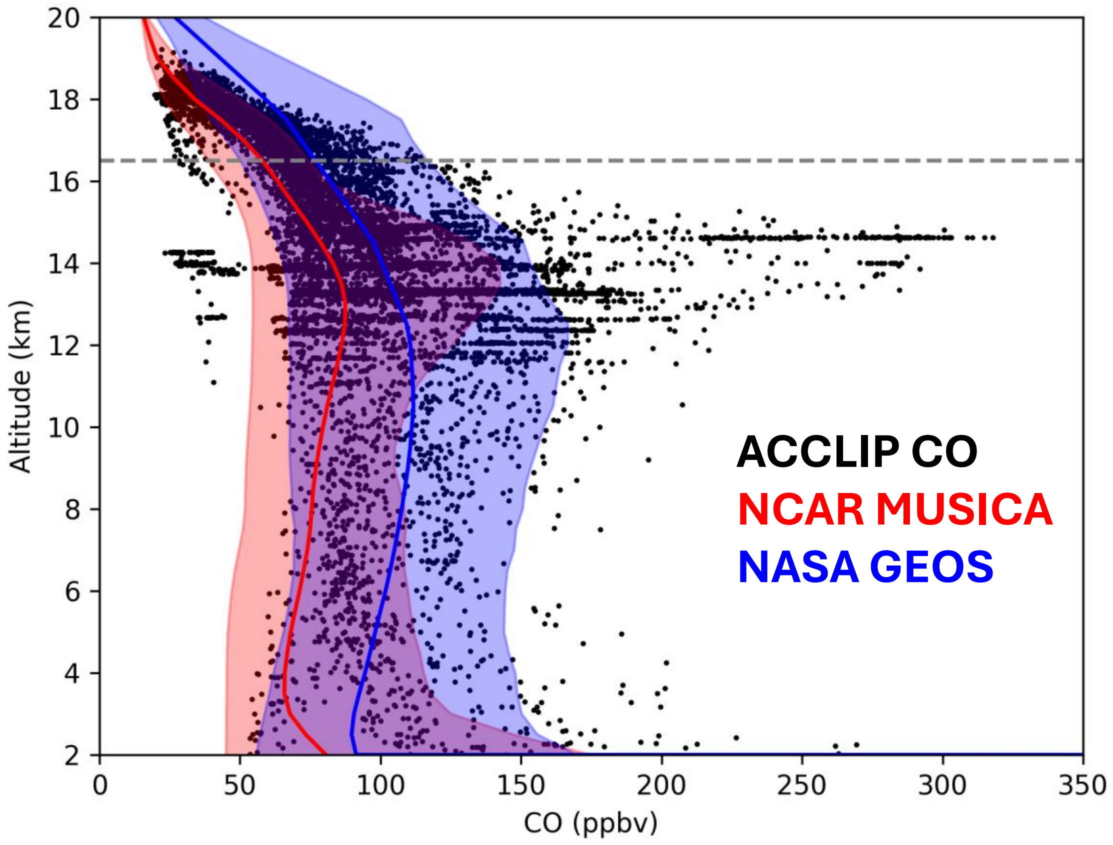


Observations of chlorinated species courtesy of the WAS team and the TOGA-ToF team

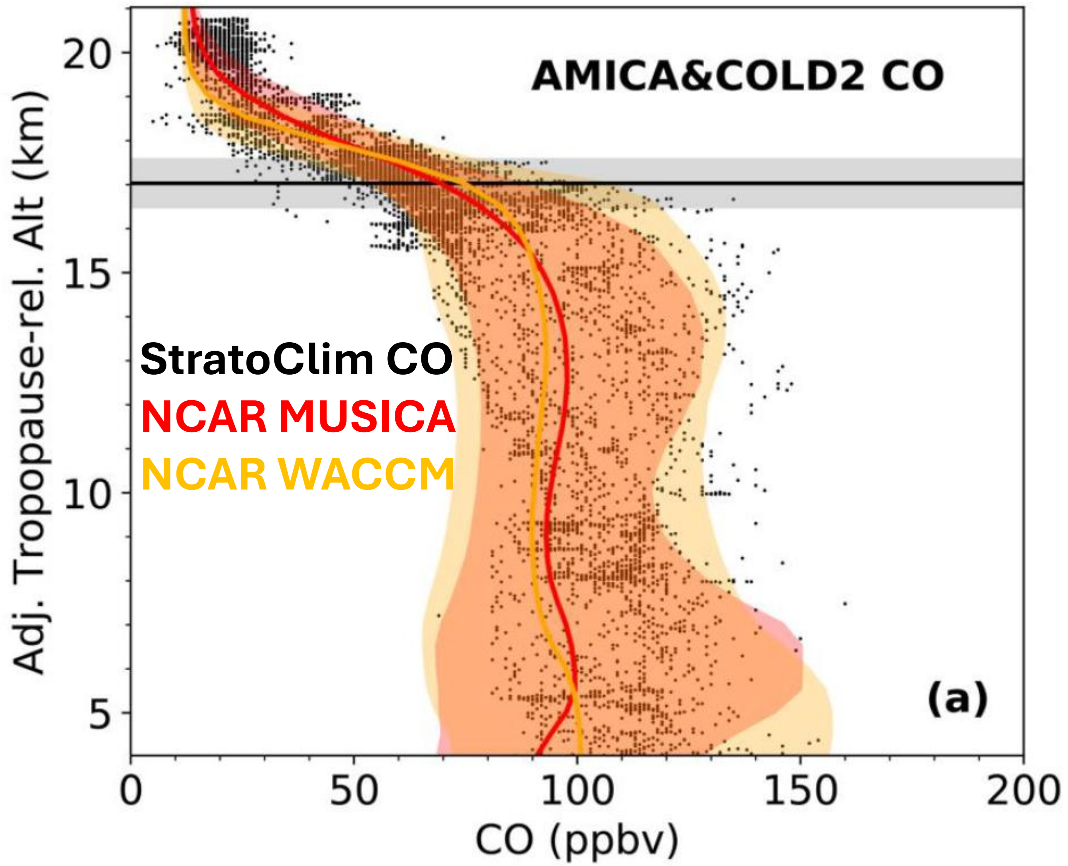


Figures courtesy of Pan et al. (2024)

In-field model forecasts did not represent the largest pollutant amounts observed

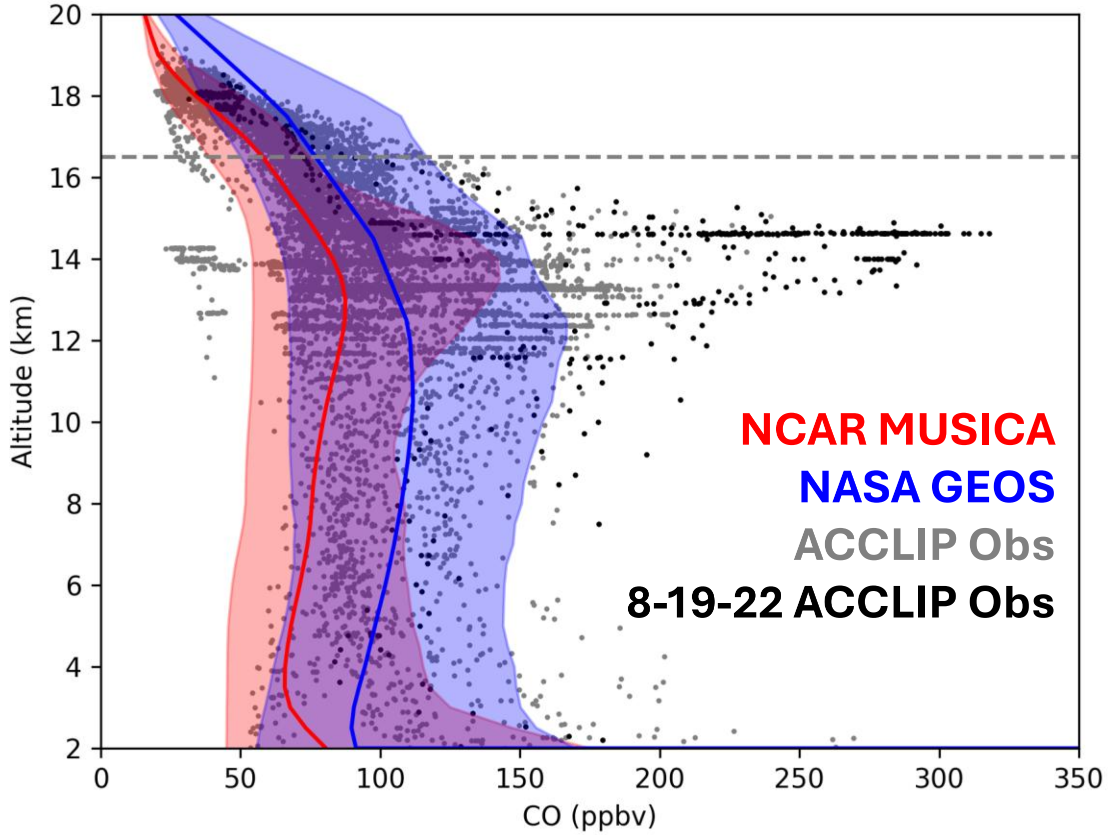


GV CO data provided by T. Campos, WB-57 CO data provided by S. Viciani and the COLD2 instrument team

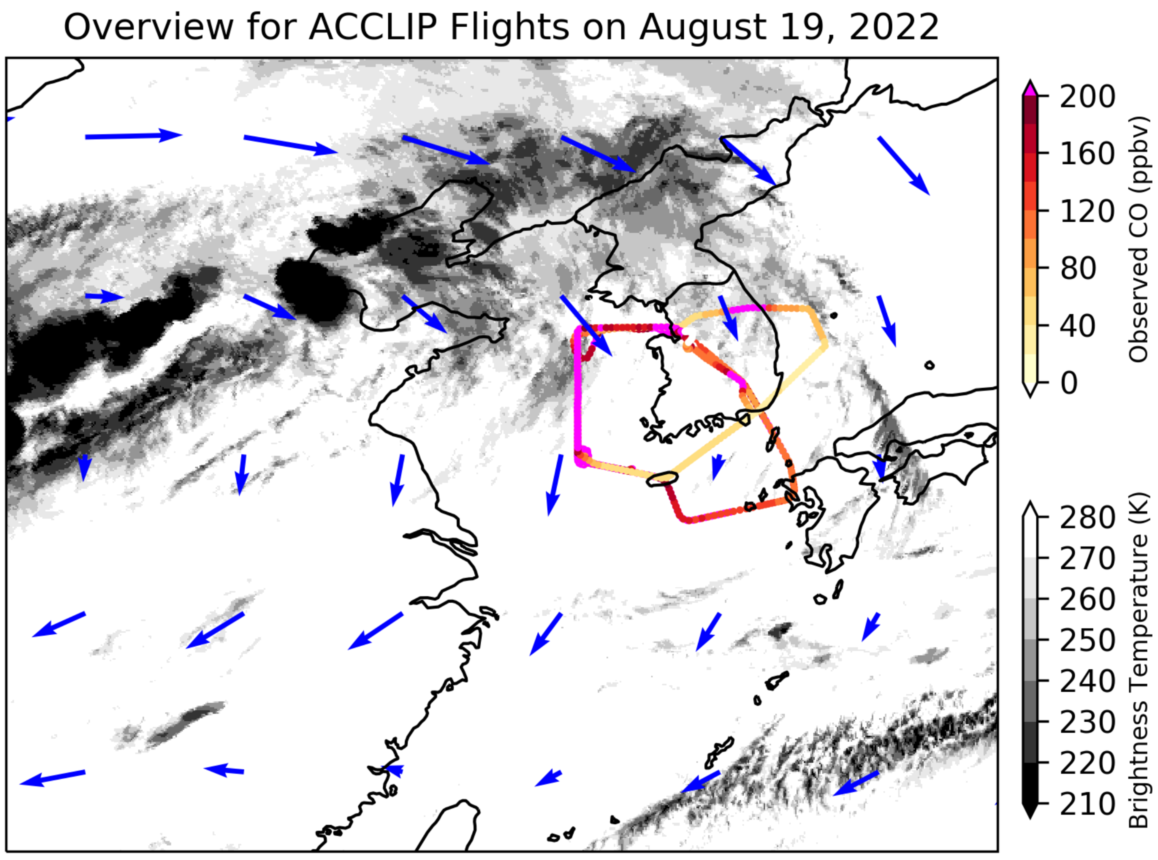


From Smith et al. (2024)

Transport by deep convection is essential for representing these pollutant concentrations



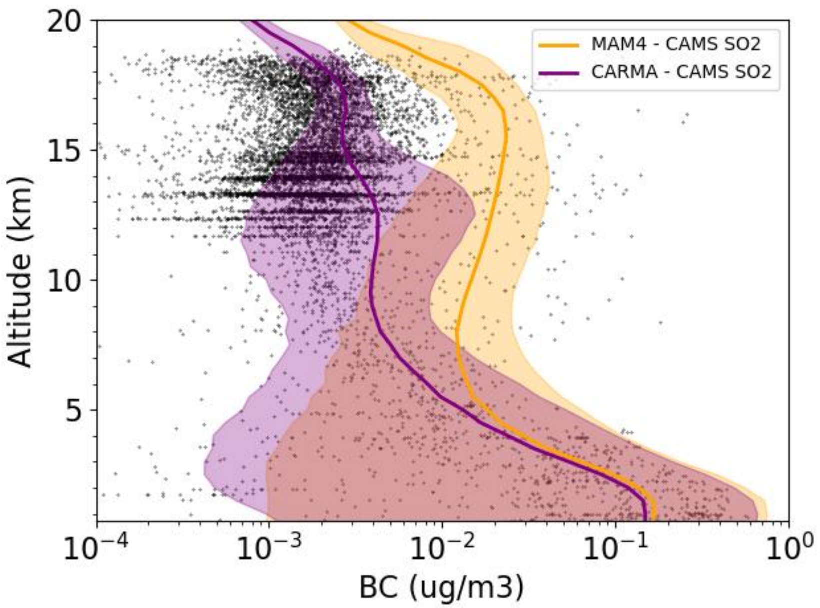
GV CO data provided by T. Campos, WB-57 CO data provided by S. Viciani and the COLD2 instrument team



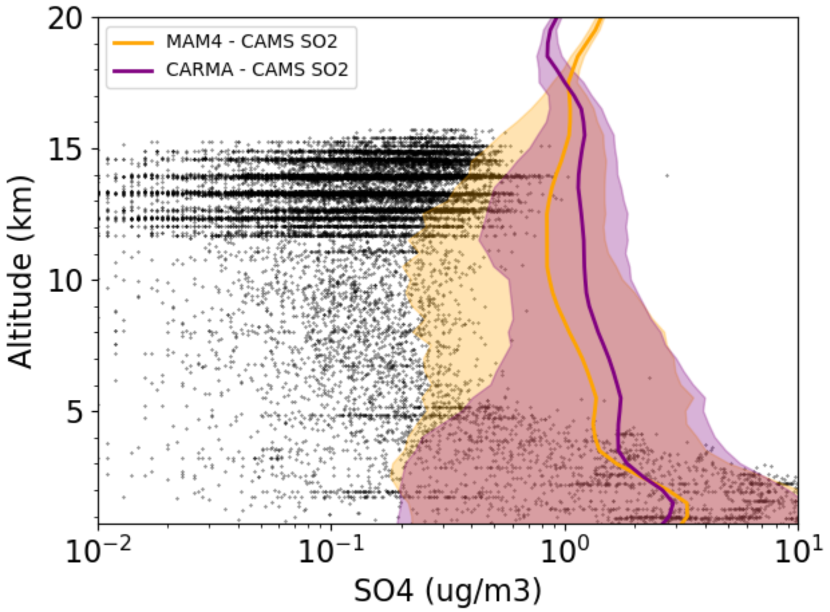
Pink shows CO > 200 ppbv along flight track

We evaluate UTLS aerosol concentrations in CESM2 using ACCLIP airborne observations

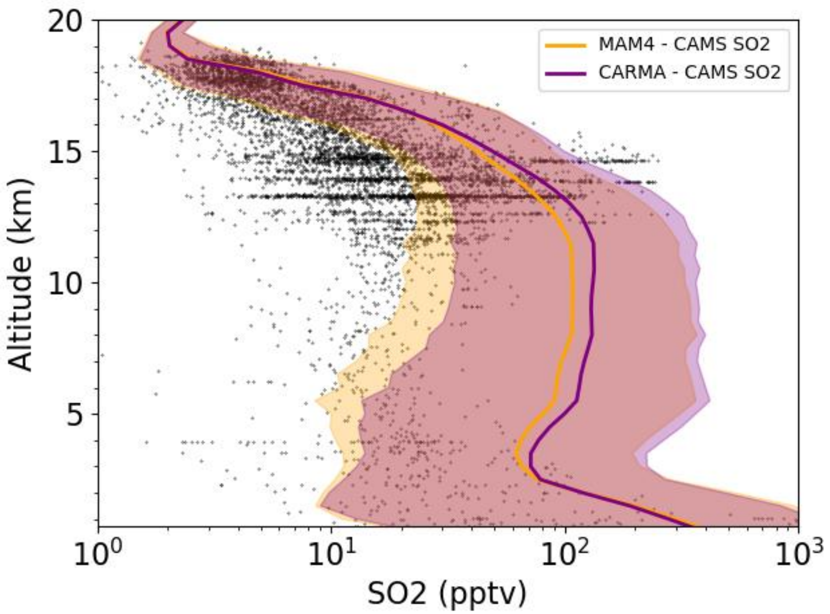
Here we evaluate the impact of aerosol model complexity, comparing simulations using a simple **modal aerosol model (MAM4)** with the more complex **CARMA aerosol model**



Black carbon aerosol is quantifiably improved with the CARMA aerosol model!



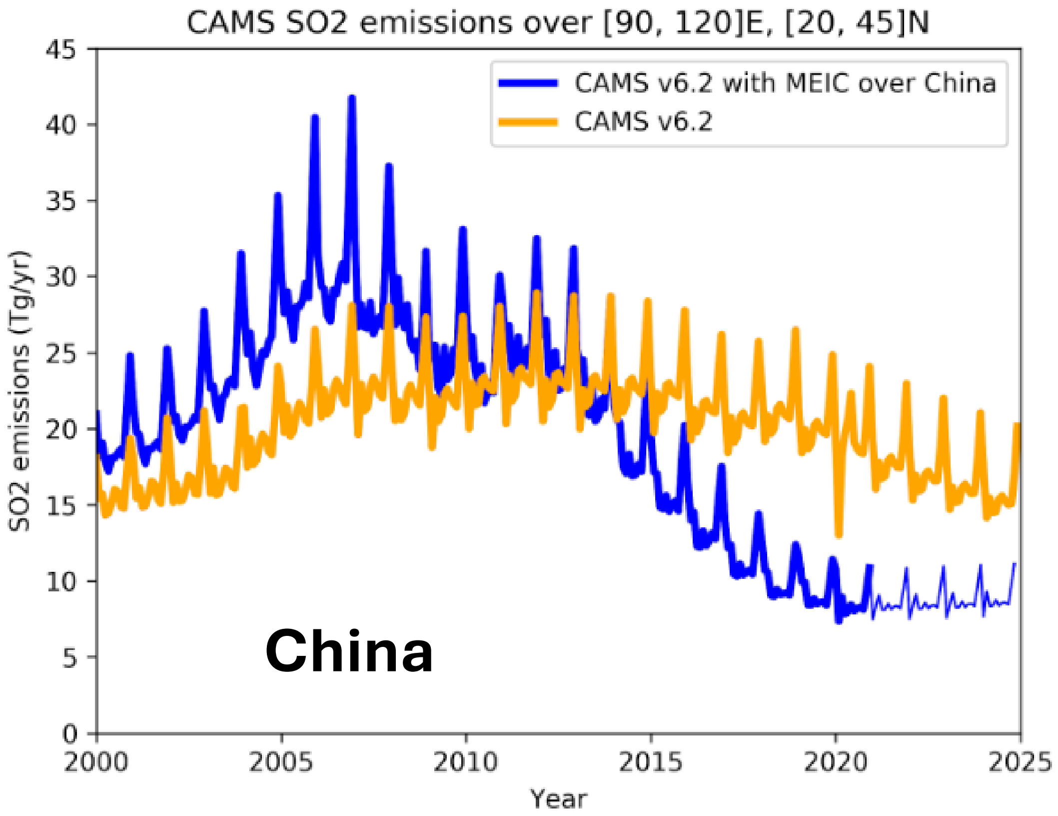
Sulfate aerosol shows a high bias in both simulations

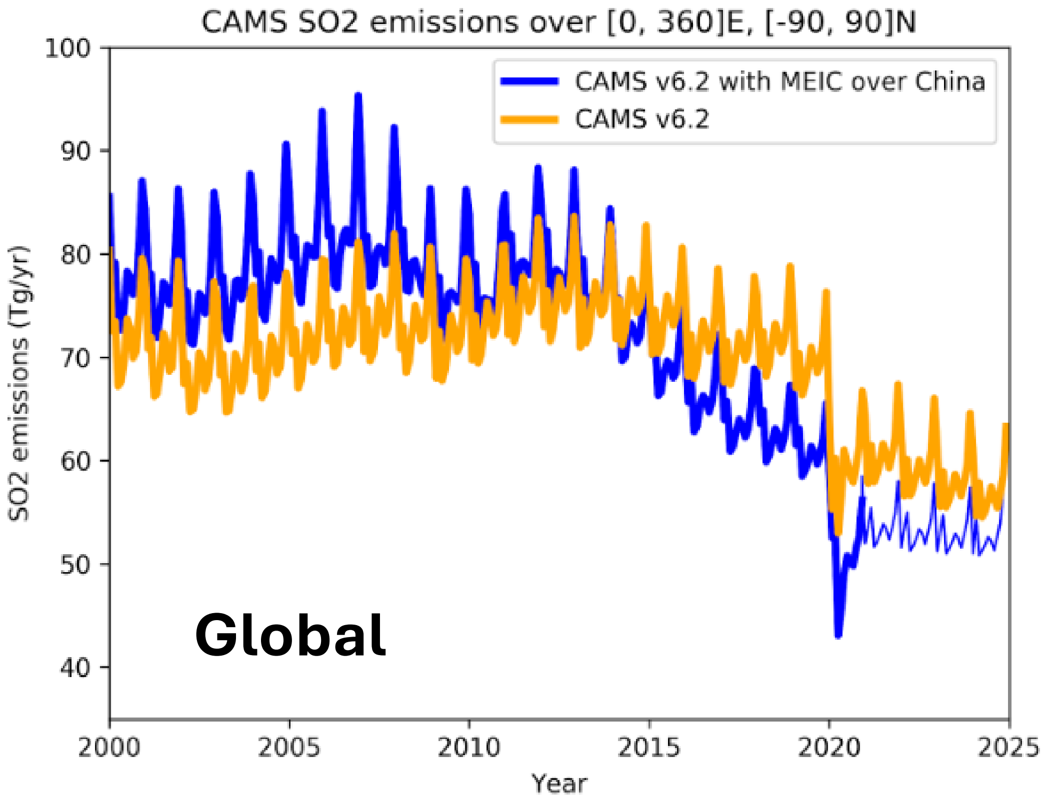


Sure enough, there is also a high bias in SO_2, a sulfate precursor gas

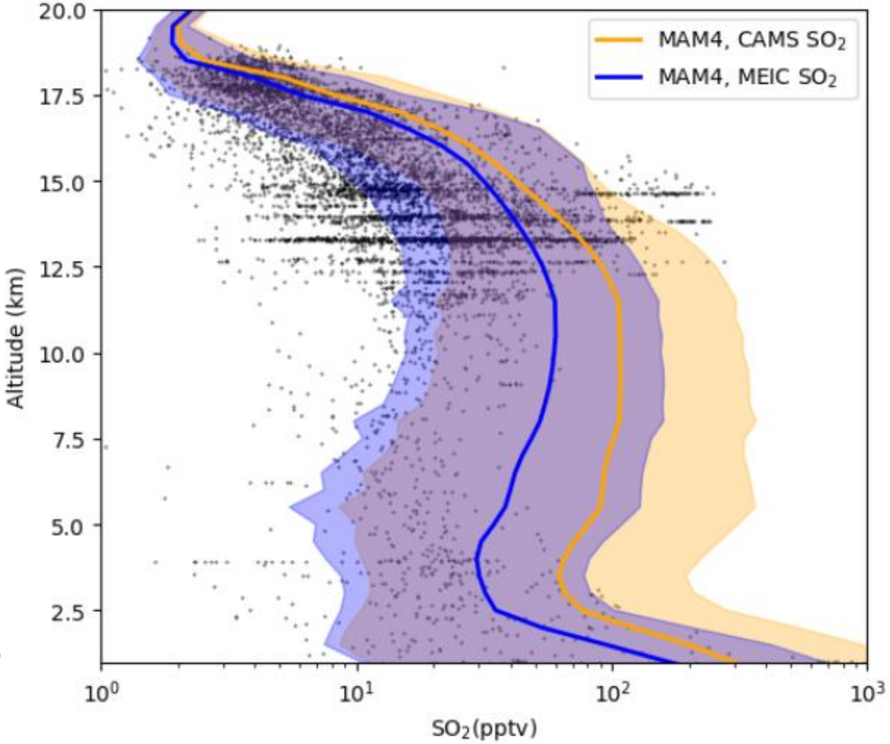
Airborne observations courtesy of the SP2 team (BC), ERICA team (SO_4) and the LIF and GT-CIMS teams (SO_2)

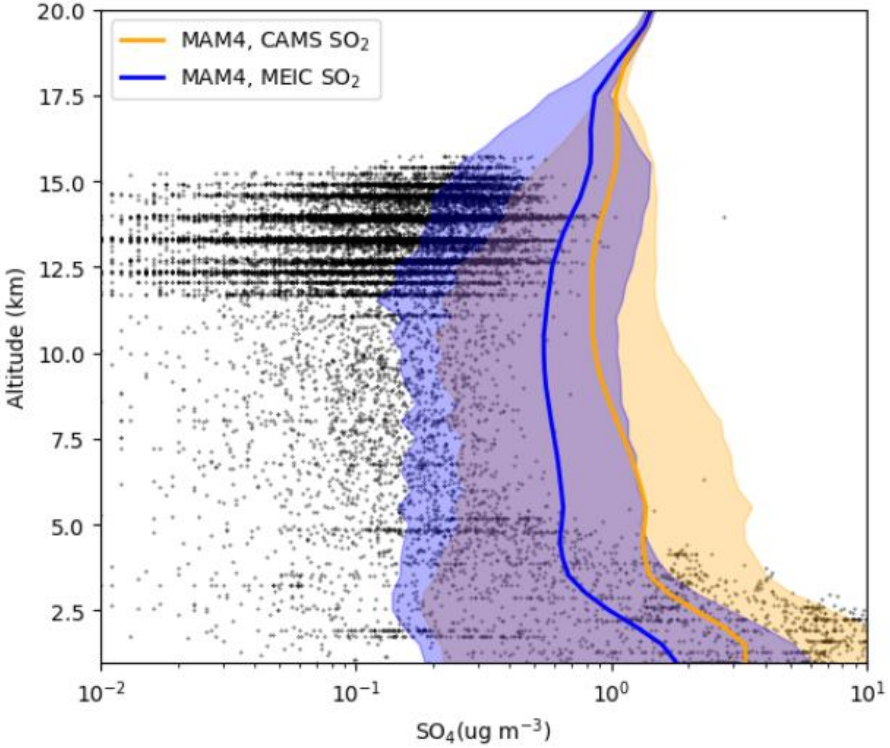
Emissions databases do not agree on the extent of recent SO_2 reductions in China





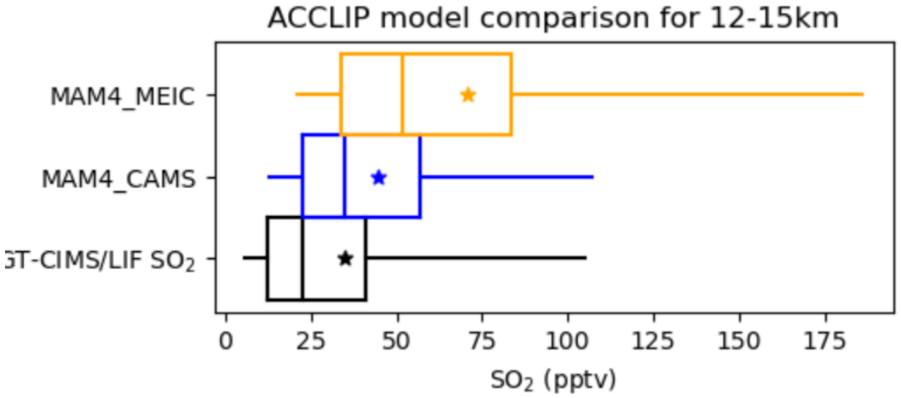
Emissions reductions improve both SO_2 and sulfate aerosol representation

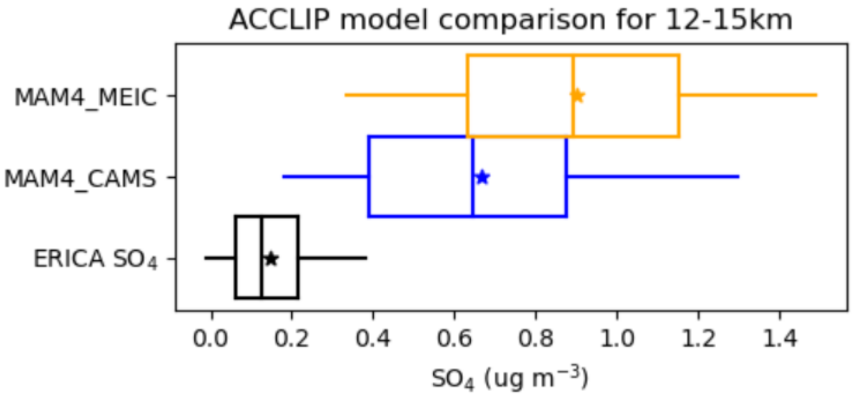




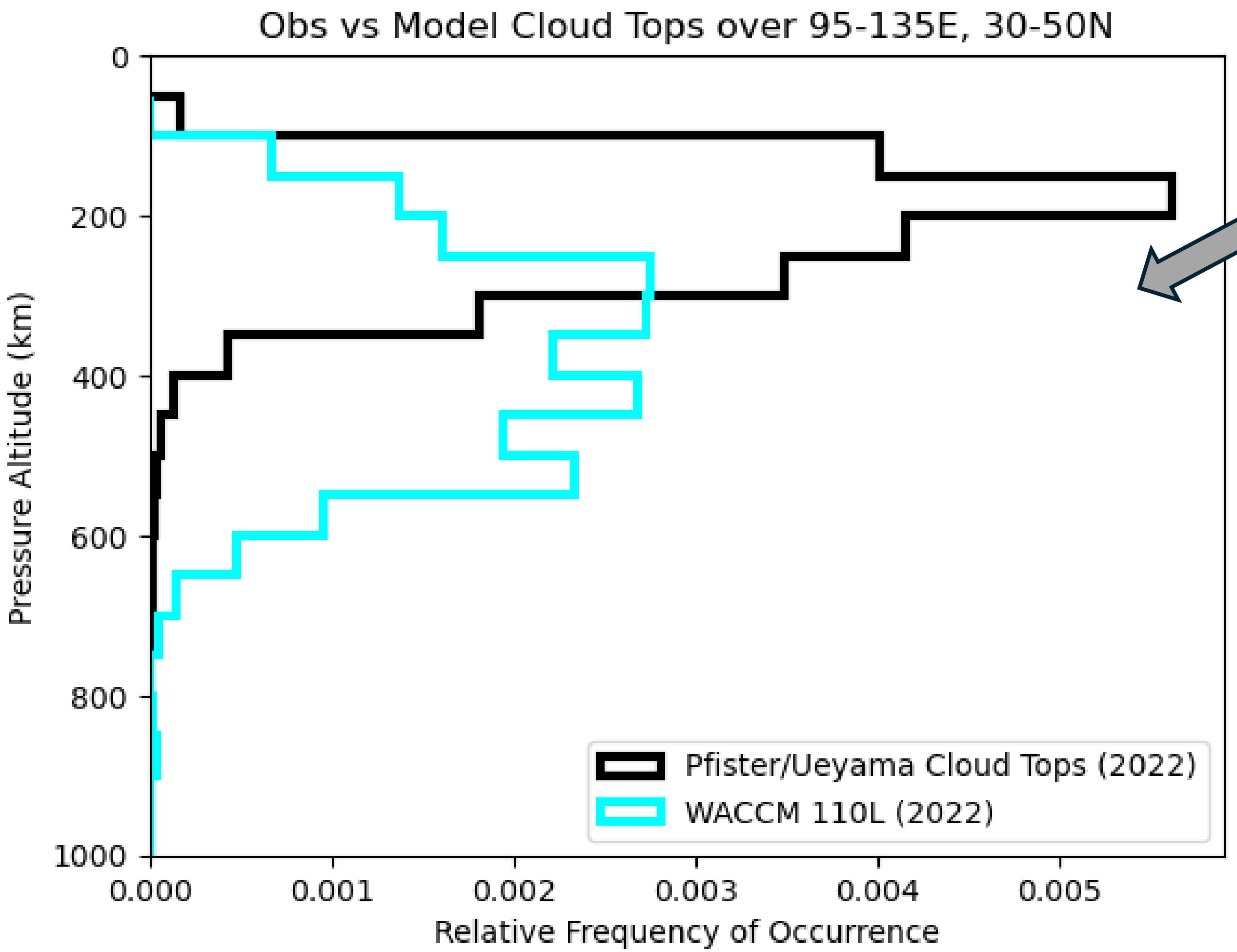
Airborne observations courtesy of the ERICA team (SO_4) and the LIF and GT-CIMS teams (SO_2)

12-15km Distributions





Model convection over the East Asian monsoon is not deep enough



Low bias in model depth of convection

↓ ?

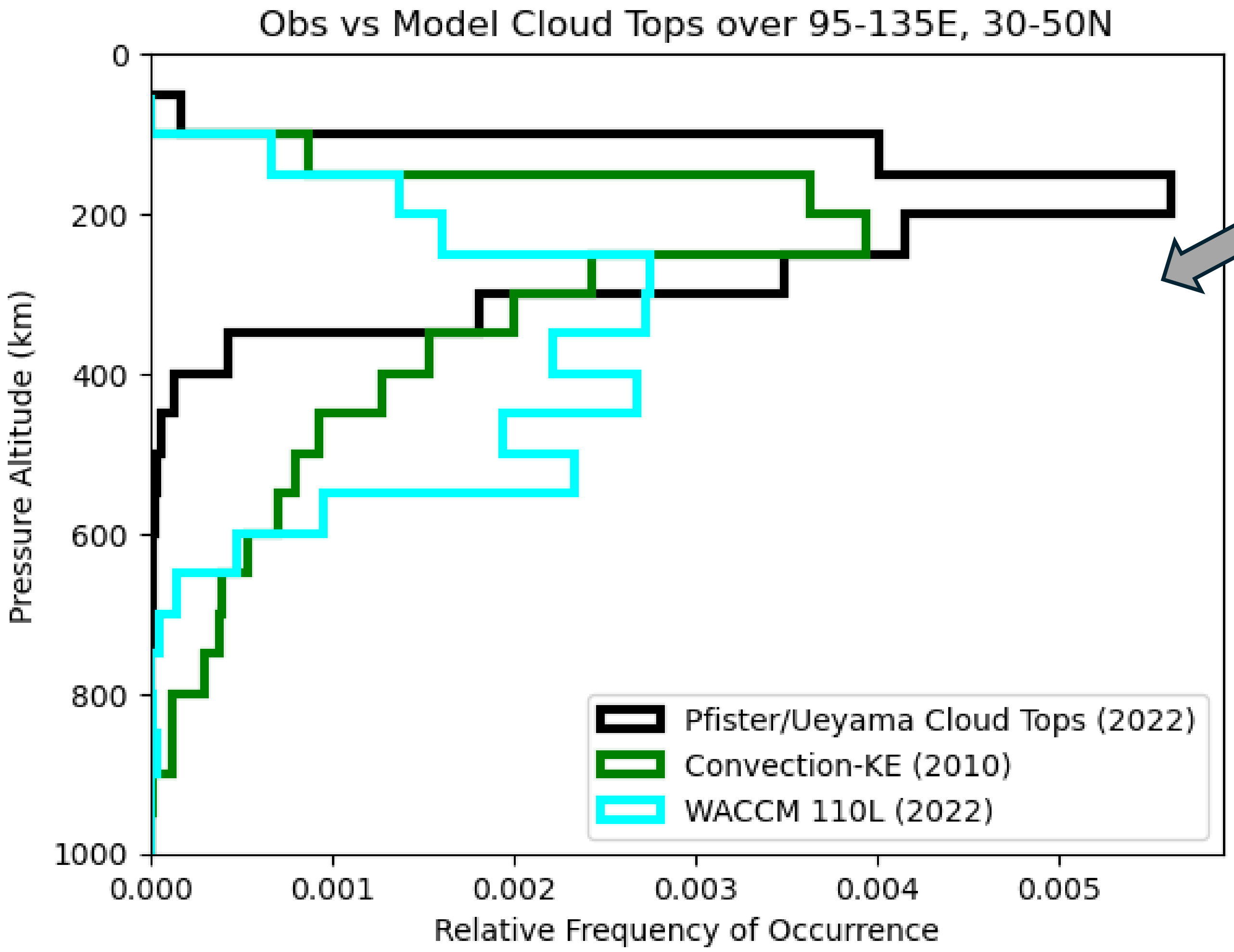
Low bias in model SO_4 wet removal (not shown)

↓ ?

High bias in model SO_4 (shown earlier)

Collaboration with Rich Neale and Simone Tilmes at NCAR

Model convection over the East Asian monsoon is not deep enough



Low bias in model depth of convection

↓ ?

Low bias in model SO_4 wet removal (not shown)

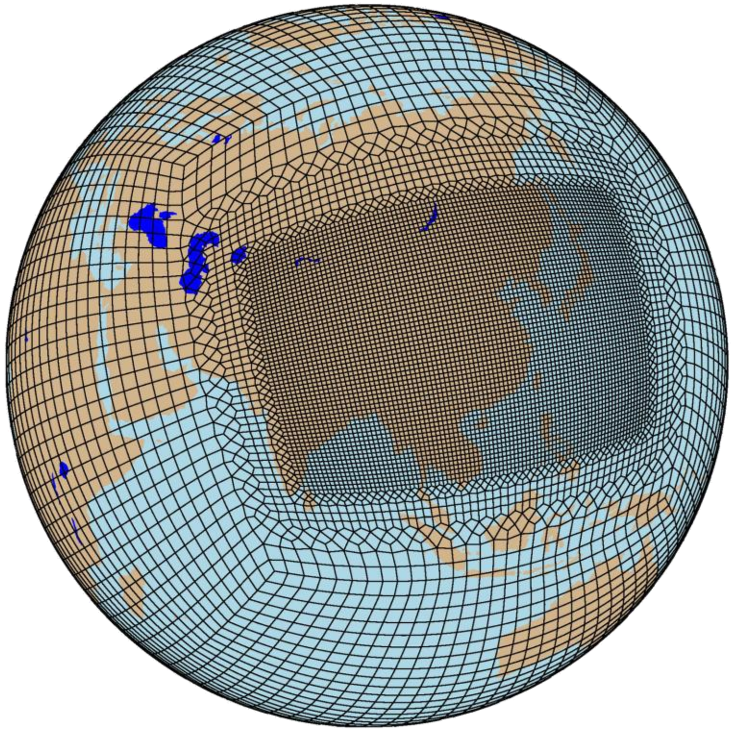
↓ ?

High bias in model SO_4 (shown earlier)

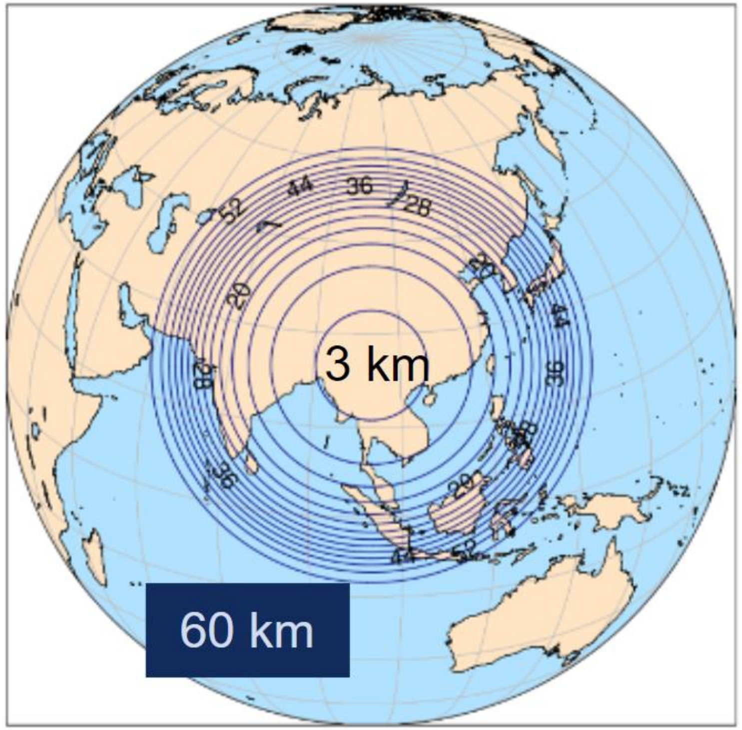
The new convection scheme in CESM3 (**green**) shows a promising indication that this representation may be improved in future climate modeling

Collaboration with Rich Neale and Simone Tilmes at NCAR

Enhanced grid capabilities are also expected to yield improvements in convective transport representation

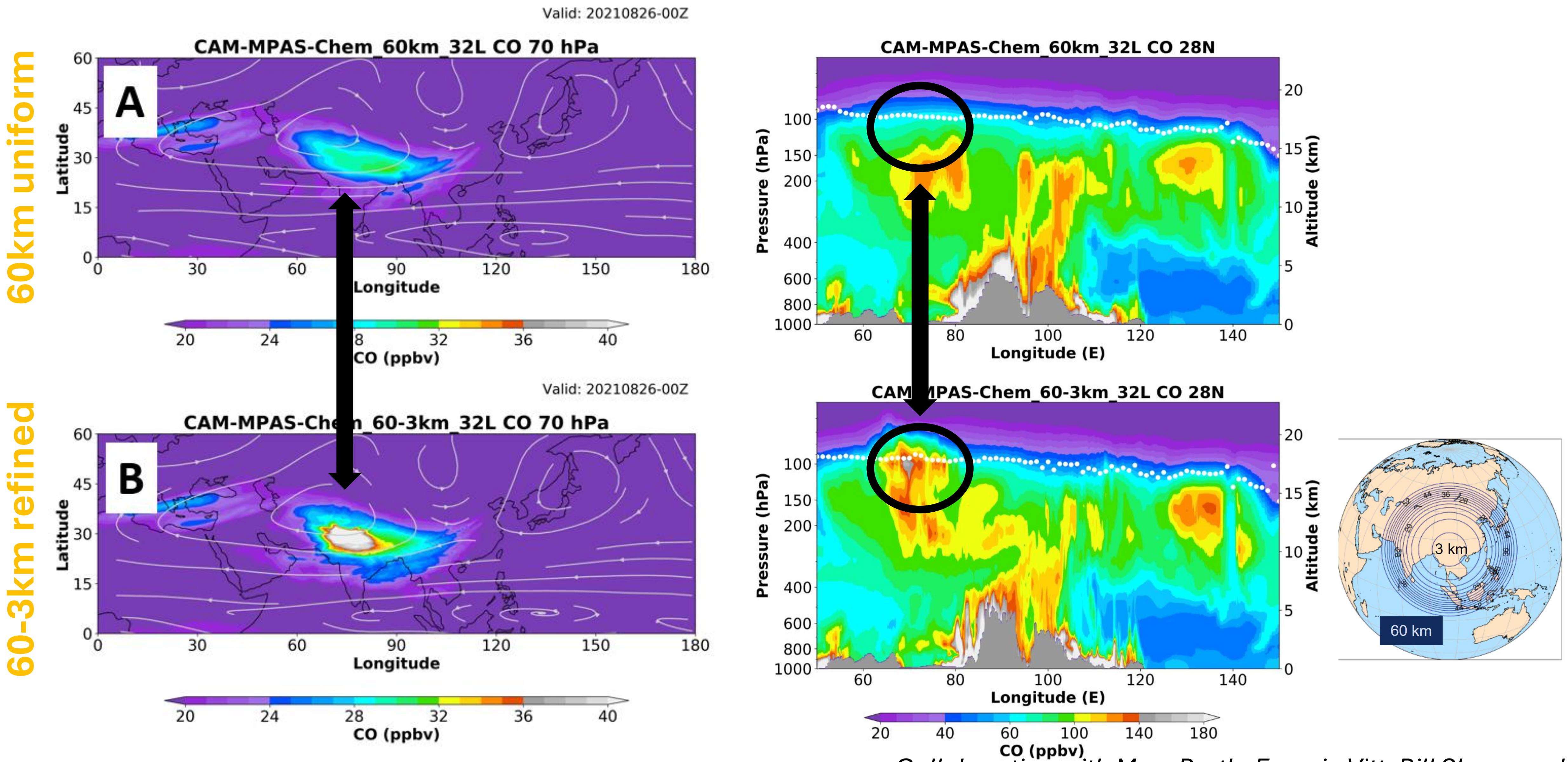


MUSICA version 0
Spectral element dynamical core
Hydrostatic



MUSICA version 1
MPAS dynamical core
Non-hydrostatic

Regional refinement increases transport to the UTLS



Collaboration with Mary Barth, Francis Vitt, Bill Skamarock

Take-home messages

- The Asian Summer Monsoon is important for affecting UTLS composition, a mechanism which may have global impacts
- The specific importance of the East Asian Summer Monsoon has been discovered by recent airborne measurements (ACCLIP 2022)
  - Air masses associated with this sub-system were generally more polluted than those transported or measured directly over South Asia
- In-field forecast models do not represent the largest pollutant levels observed in the UT during ACCLIP
- The model representation of sulfate aerosol is improved by using a Chinese emissions inventory for SO_2, and the remaining bias may require improvements to the representation of deep convection

Science Outlook

- The convective transport diagnostic is available for use by the research community, and a manuscript summary is in review
- Additional airborne measurements were taken over the central north Pacific during PHILEAS (2023) to study export of ASM air, research should link campaigns for a comprehensive picture
- Additional ACCLIP campaign science is ongoing, including studies on black carbon wet removal, the ASM sulfur budget, and new particle formation
- Our science team welcomes new research ideas using new tools and techniques. Satellite observations are particularly useful given the multi-scale nature of this transport problem

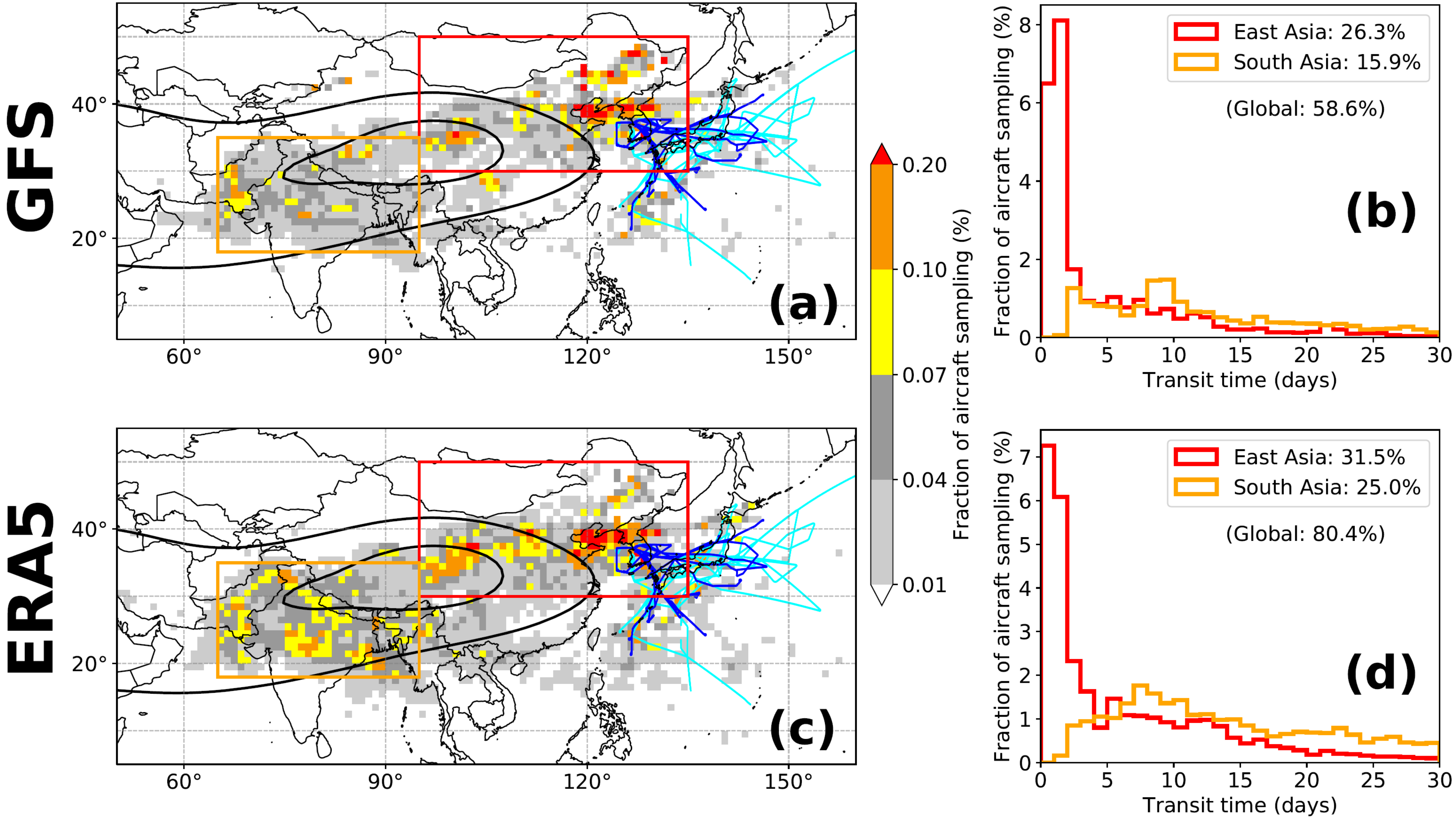
ACCLIP
NOAA • NSF • Western Pacific 2022 • NASA • ONR

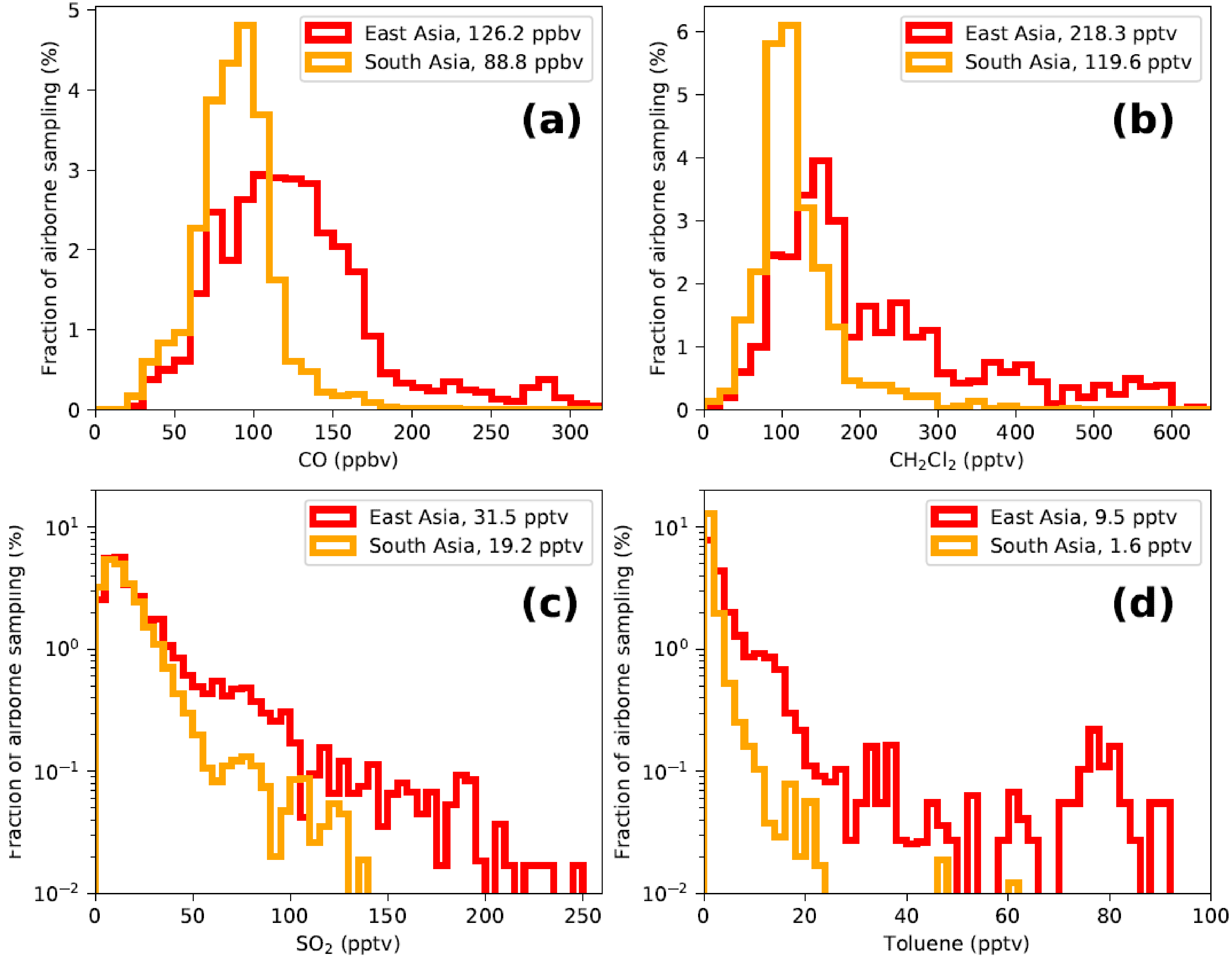
Thank you!

wsmith@ucar.edu

ACCLIP Airborne Measurements

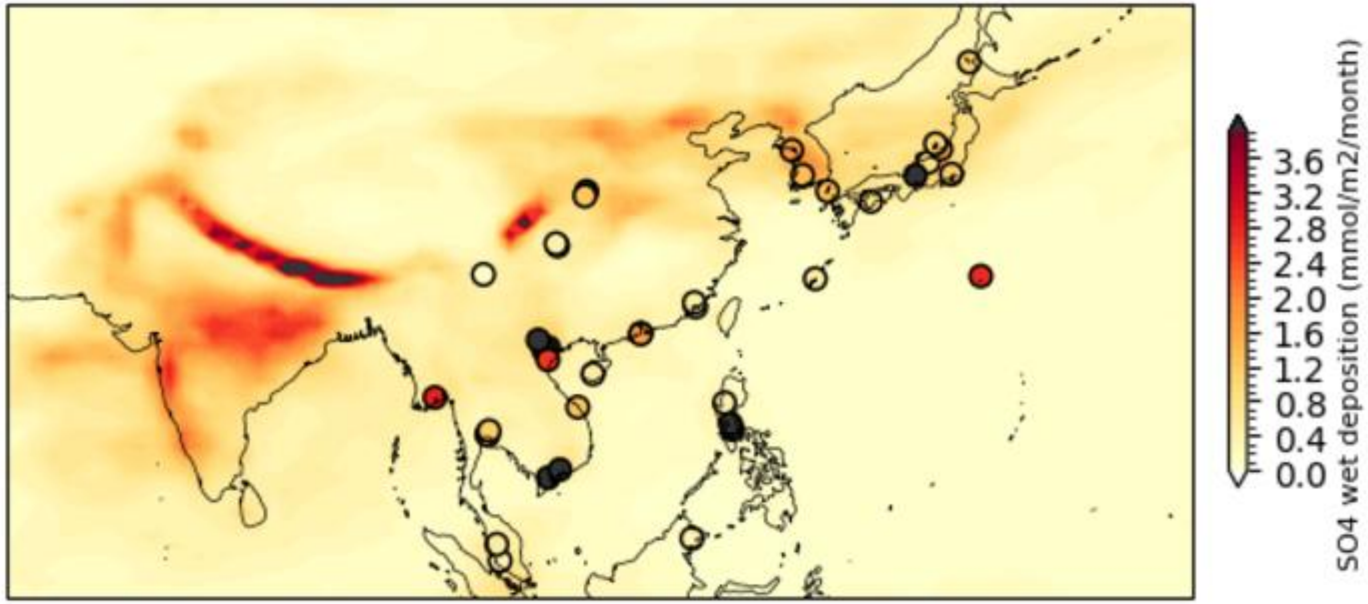
Measurement	WB	GV
State Parameters		
Position, Pressure, Temperature, Winds, Humidity	Aircraft, MMS	Aircraft, VCSEL
Temperature profile (above/below aircraft)		MTP
Trace Gases		
CO	COMA, COLD2, ACOS	Aerodyne, Picarro
CO_2	ACOS	Picarro
CH_4		Picarro
N_2O	COMA	Aerodyne
O_3	UAS O3	FAST_O3
NO, NO_2	NO-LIF	NO_NOy
SO_2	SO2-LIF	GTCIMS
HCl, HO_2NO_2, HNO_3 HCOOH, CH_3COOH		GTCIMS
CH_2O	ISAF	TOGA
COS	ACOS	AWAS
H_2O	DLH, CHiWIS, ACOS	VCSEL
H_2O Isotopes	ChiWIS	
VOCs (many)	WAS	TOGA, AWAS
Aerosols		
Particle size/mass distributions	NMASS, CAPS, POPS, UHSAS	NMASS, UHSAS
Chemical composition/size	PALMS	ERICA
cloud particle size/imaging	2D-S	2DS
cloud droplet size	FCDP	CDP
Cloud/aerosol distributions above/below aircraft	ROSCOE	
Radiation		
Radiative flux/Photolysis frequencies	BBR	HARP


GFS
ERA5
(a)
(b)
(c)
(d)
40°
20°
60°
90°
120°
150°
0.20
0.10
0.07
0.04
0.01
Fraction of aircraft sampling (%)
East Asia: 26.3%
South Asia: 15.9%
(Global: 58.6%)
East Asia: 31.5%
South Asia: 25.0%
(Global: 80.4%)
Transit time (days)

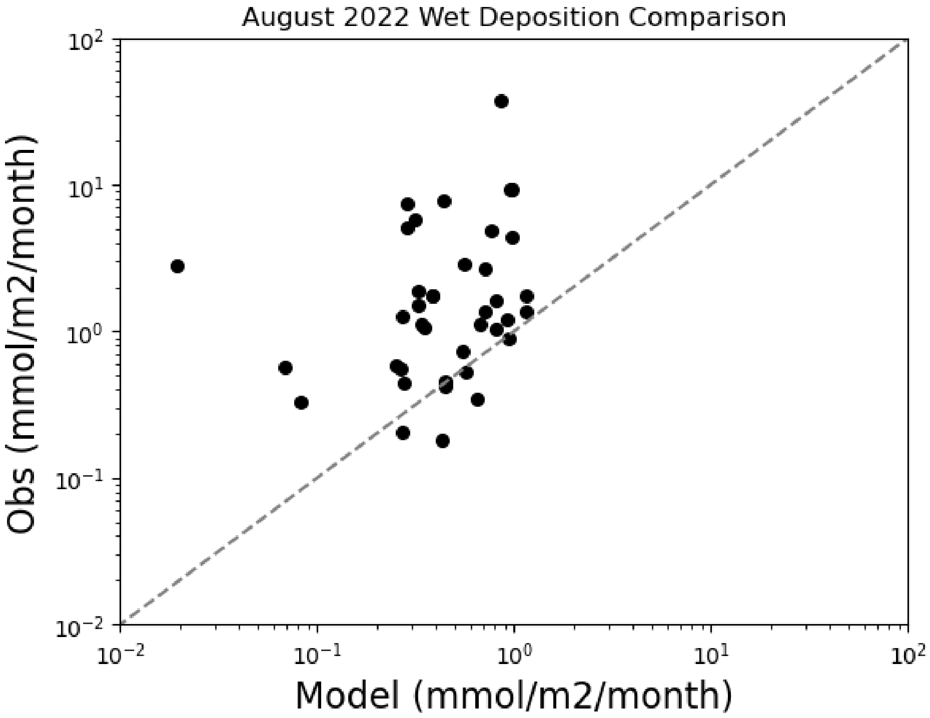


East Asia, 126.2 ppbv
South Asia, 88.8 ppbv
(a)
Fraction of airborne sampling (%)
CO (ppbv)
East Asia, 218.3 pptv
South Asia, 119.6 pptv
(b)
CH_2Cl_2 (pptv)
East Asia, 31.5 pptv
South Asia, 19.2 pptv
(c)
SO_2 (pptv)
East Asia, 9.5 pptv
South Asia, 1.6 pptv
(d)
Toluene (pptv)

Sulfate wet deposition is low in the model compared to a ground-based network

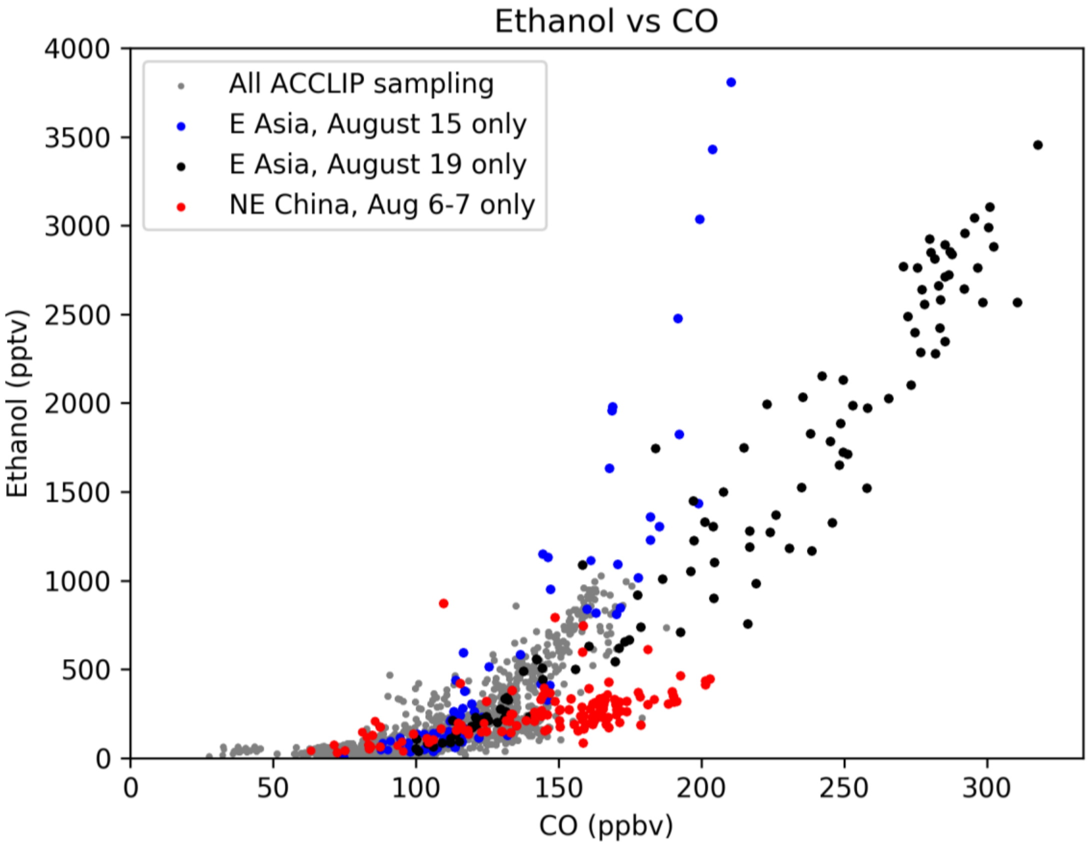


Background: CAM-Chem with MEIC emissions, Dots: Observations

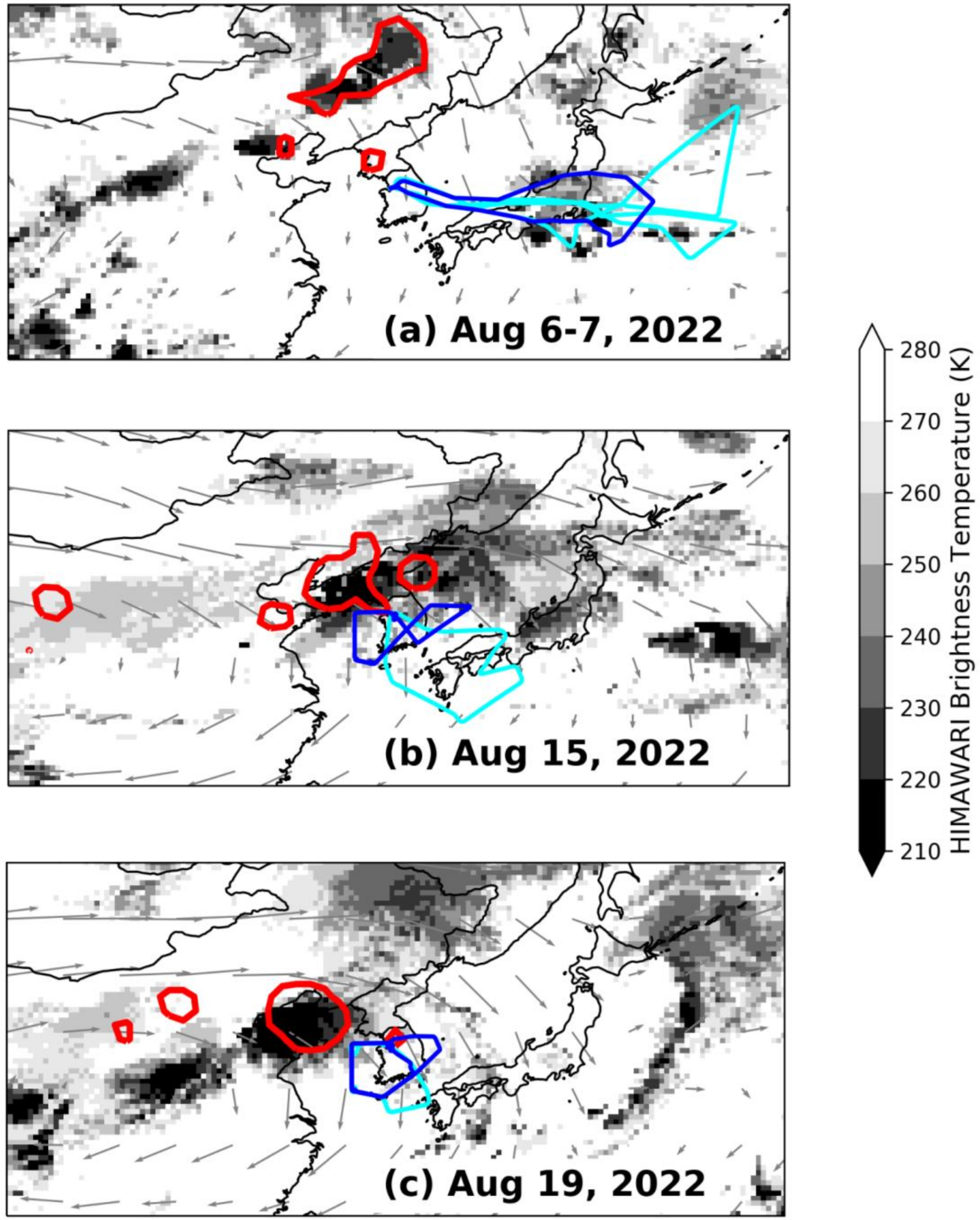


Observations courtesy of the Acid Deposition Monitoring Network in East Asia (EANET; https://www.eanet.asia/)

Three distinct chemical signatures were sampled from three MCSs over northeast China!



CO observations courtesy of: T. Campos (GV), S. Viciani and the COLD2 team (WB-57)
Ethanol observations courtesy of: E. Apel, R. Hornbrook, and the TOGA-ToF team



Smith et al. (2025, in review at JGR-Atm)