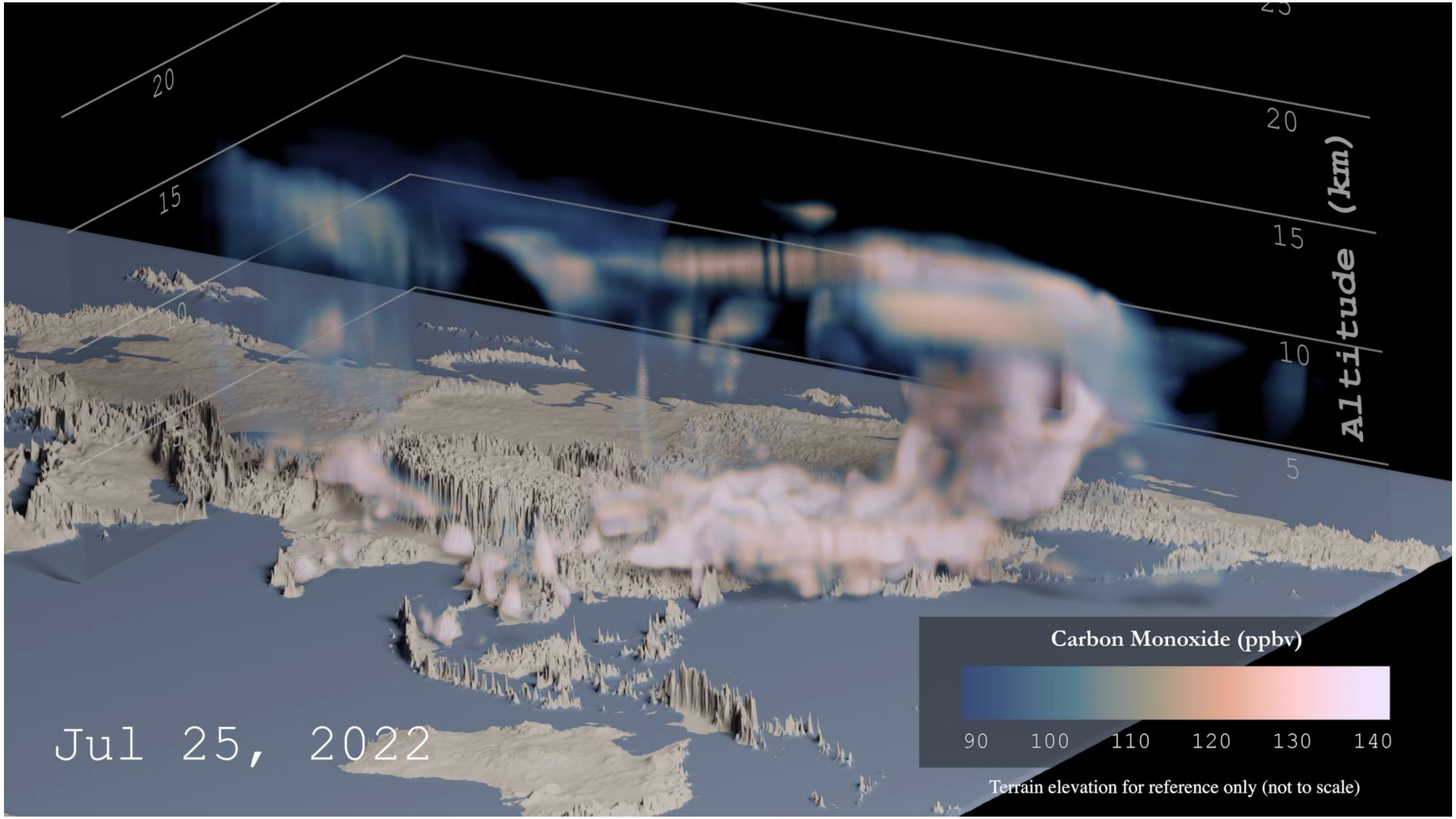
Transport by Asian Monsoon Convection to the UTLS during the 2022 ACCLIP Campaign

Dr. Warren (Ren) Smith
NSF NCAR / ACOM, Boulder, Colorado, USA
wsmith@ucar.edu

Presented at STIPMEX Workshop in Pune, India
June 4, 2024

Coauthors: Laura Pan, Rei Ueyama, Shawn Honomichl, Teresa Campos, Silvia Viciani, Francesco D'Amato, Giovanni Bianchini, Marco Barucci, Elliot Atlas and the AWAS and TOGA teams

Asian summer monsoon deep convection exports pollution to the global atmosphere



3D MUSICA rendering by Matt Rehme, NSF NCAR/CISL

Link to animation

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

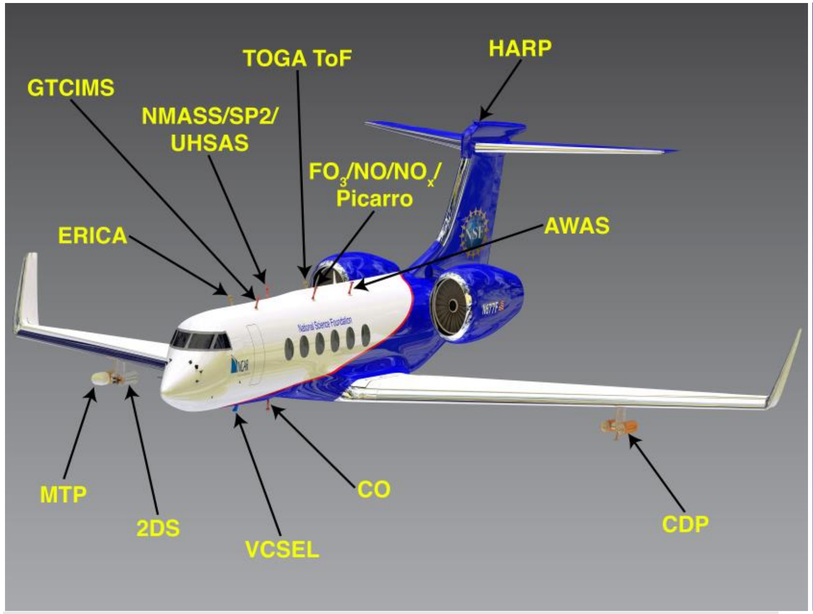
Scientific Objectives: Obtain a comprehensive suite of dynamical, chemical and microphysical measurements in the region of ASM anticyclone to address:

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

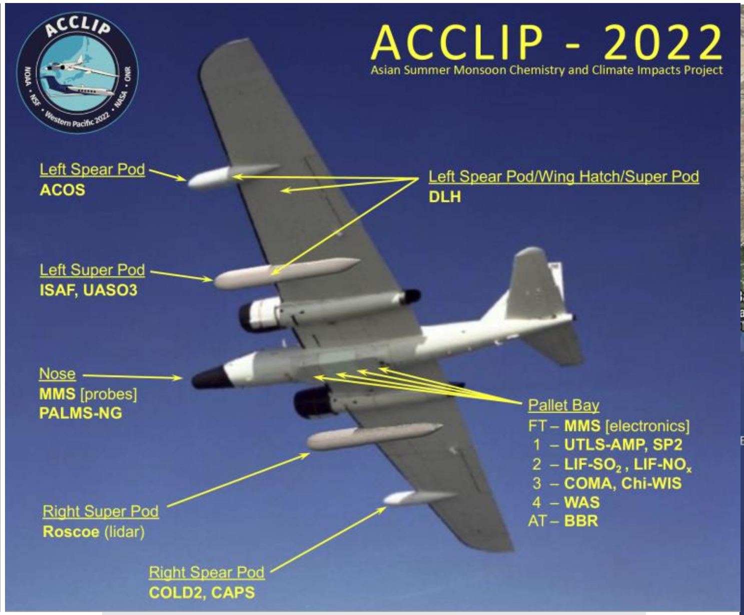
Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

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)



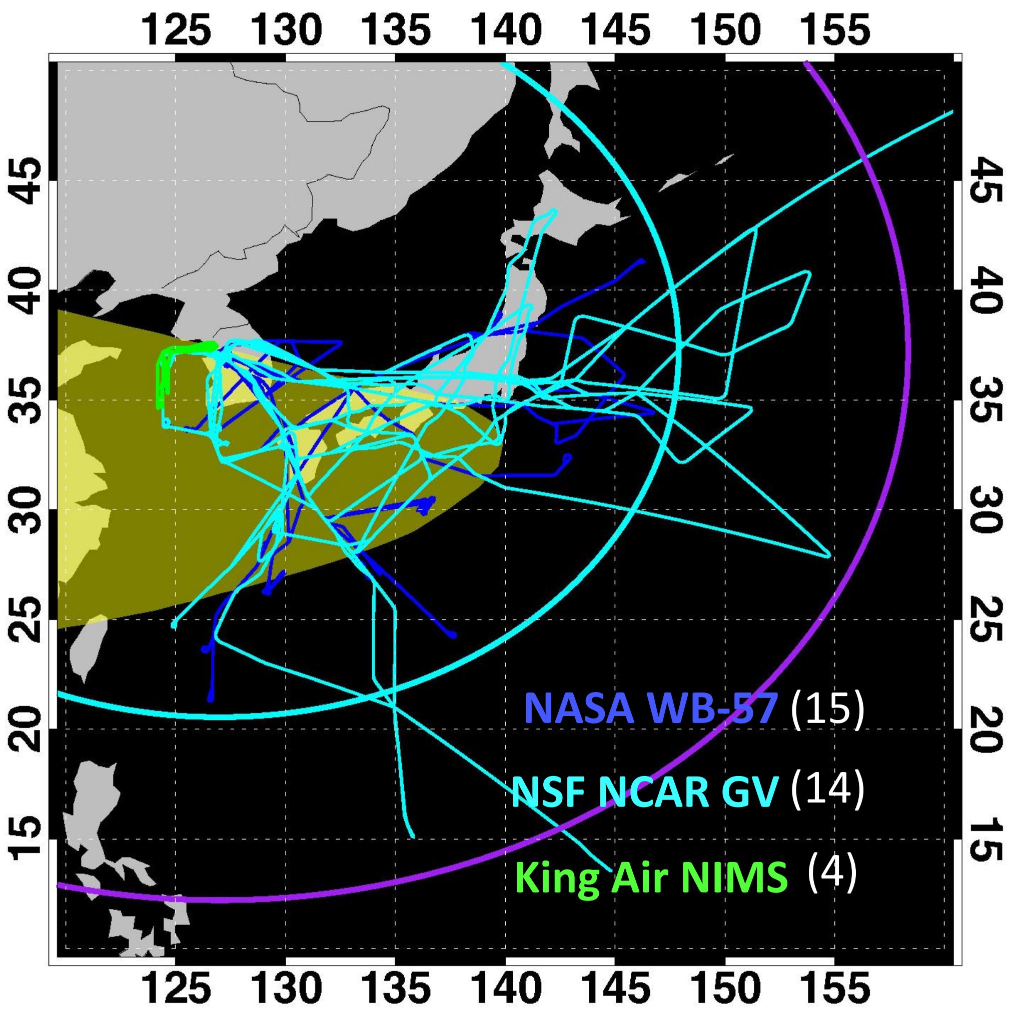
NASA WB-57
Duration: ~ 6 hr
FL 430 (13 km) and FL 620 (19 km)

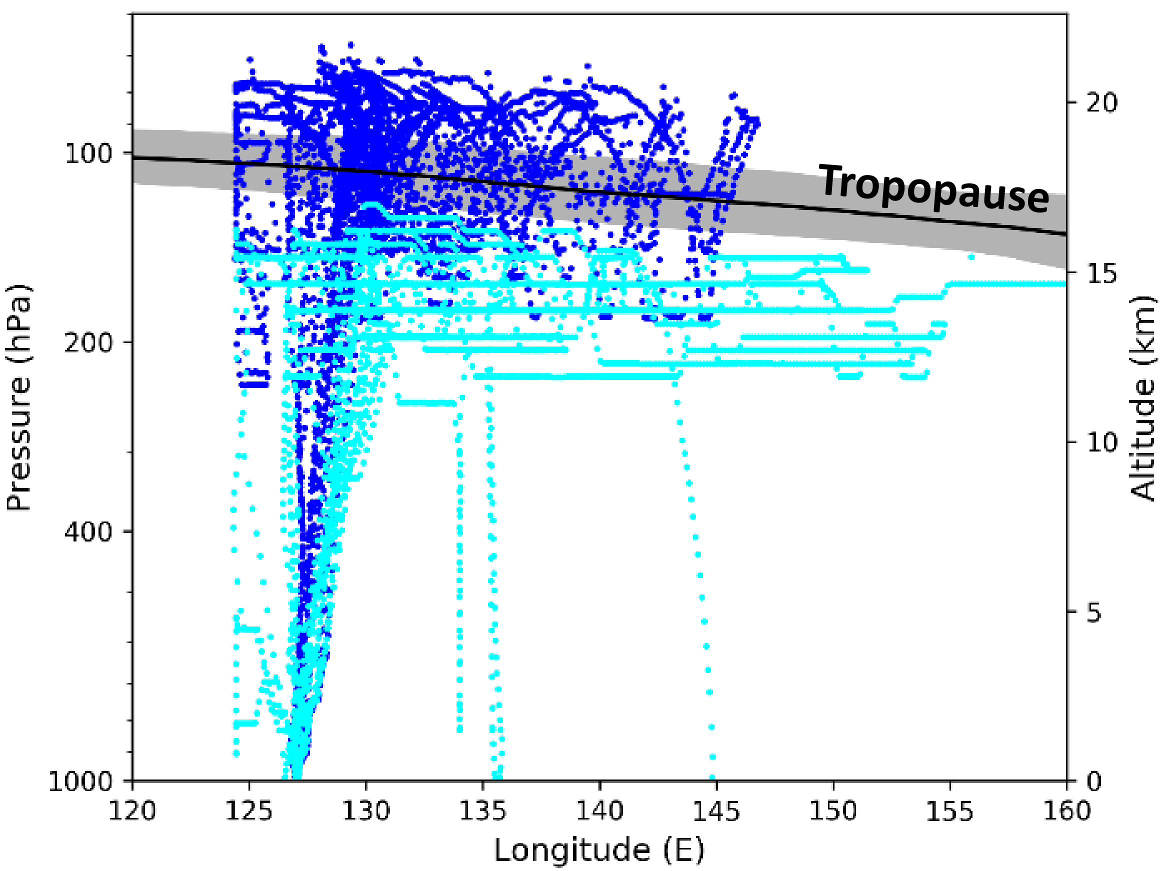
Ground Based Soundings

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)

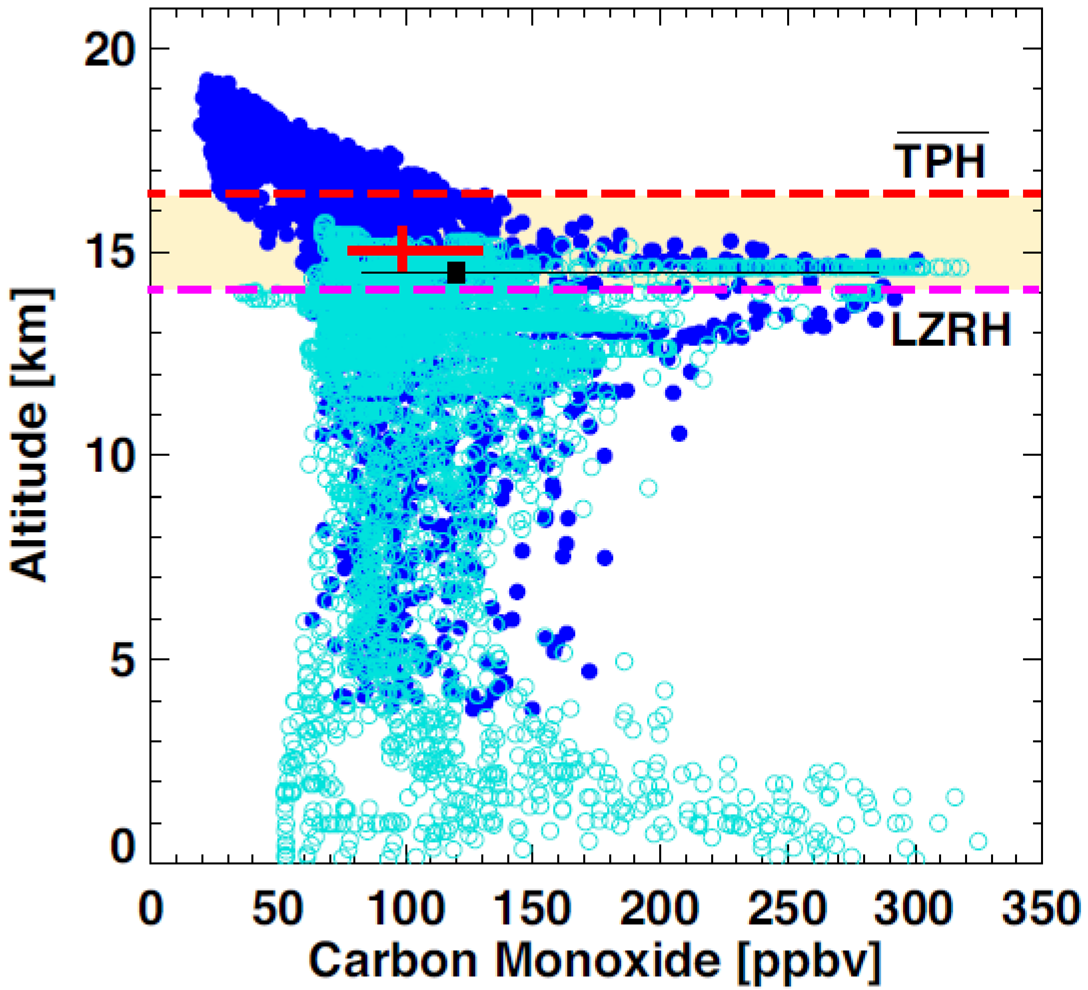


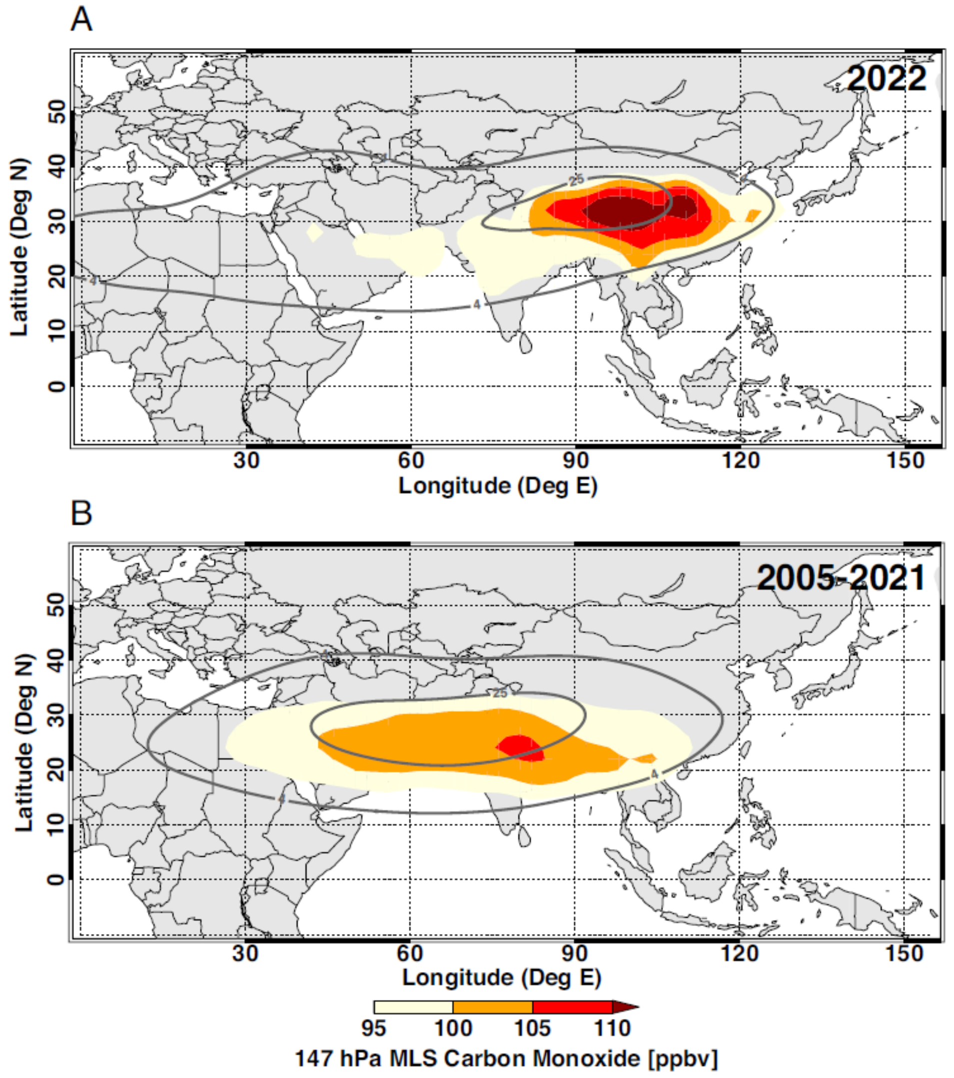


Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP)

ACCLIP Team at Osan AFB, Republic of Korea, July – September 2022

ACCLIP sampled unprecedented pollution mixing ratios in the UTLS





Figures courtesy of Pan et al. (2024)

In-field model forecasts do not represent the largest pollution mixing ratios observed

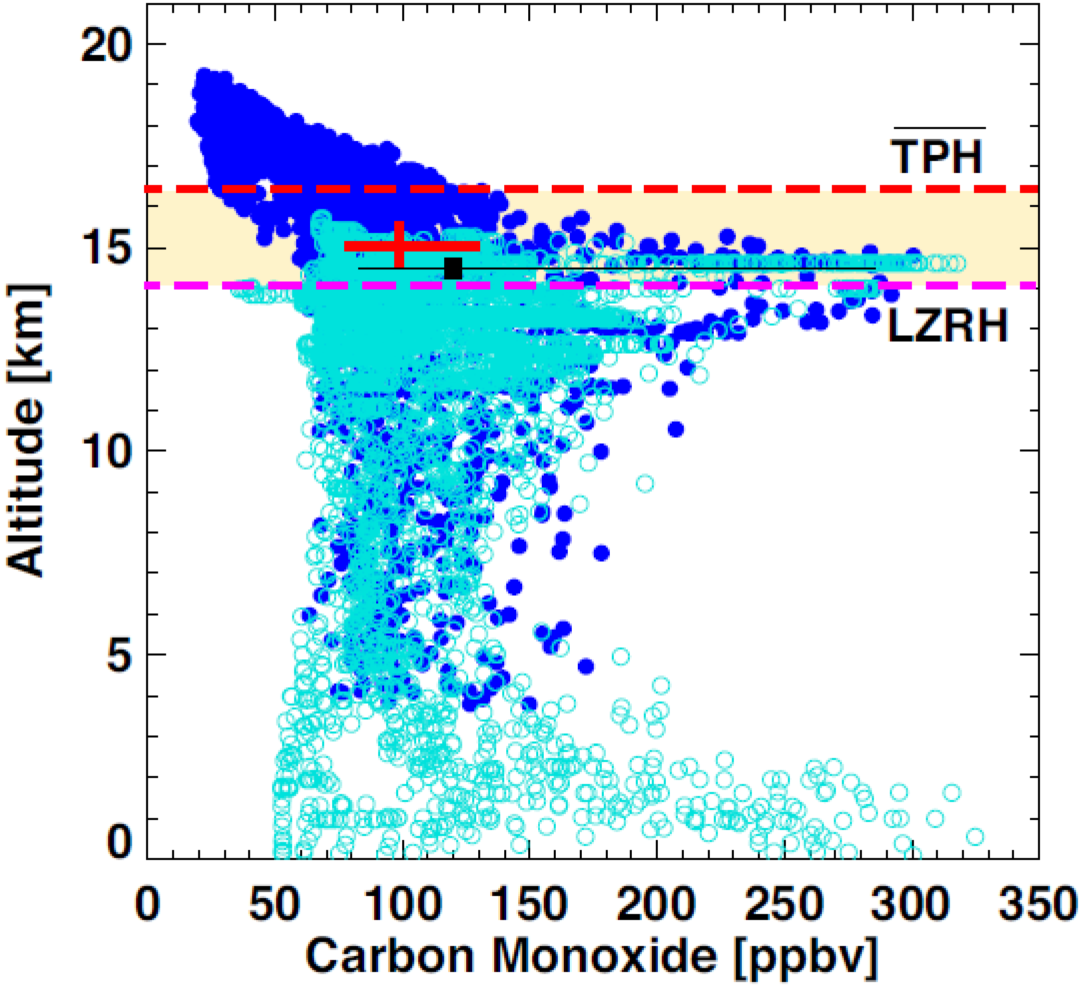
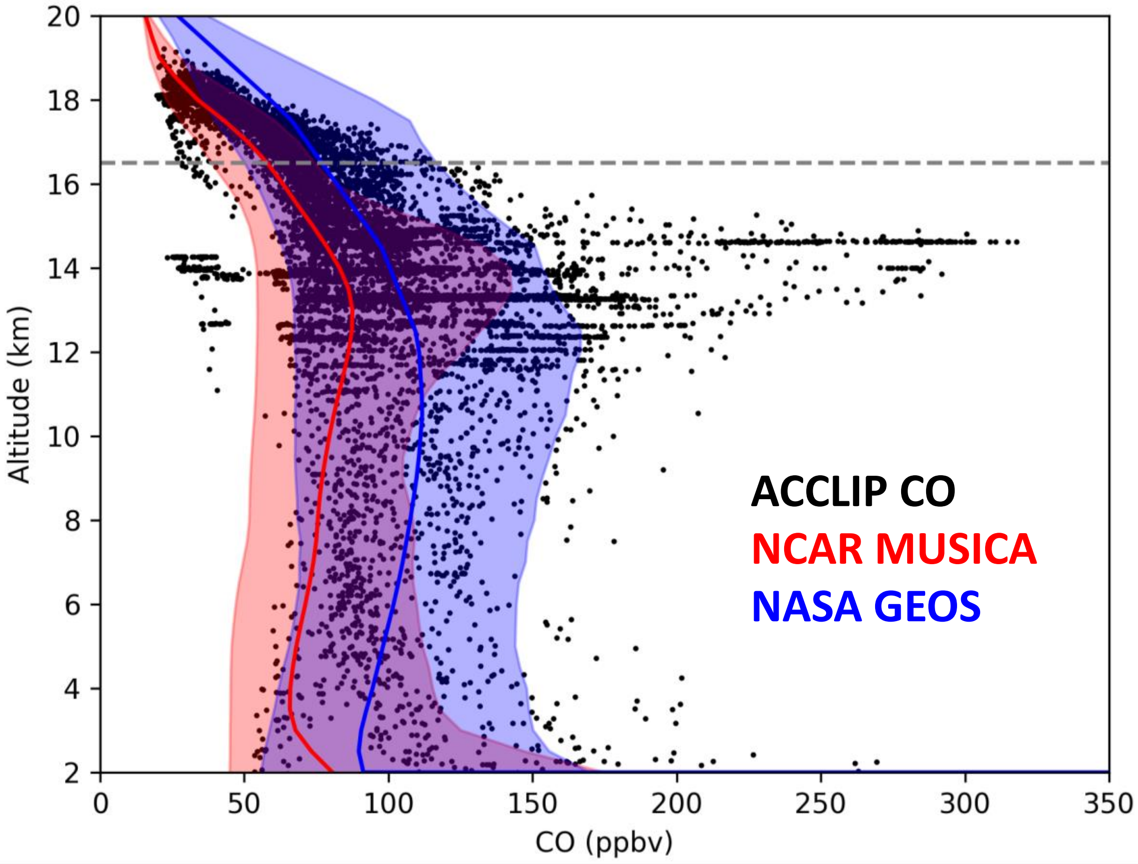
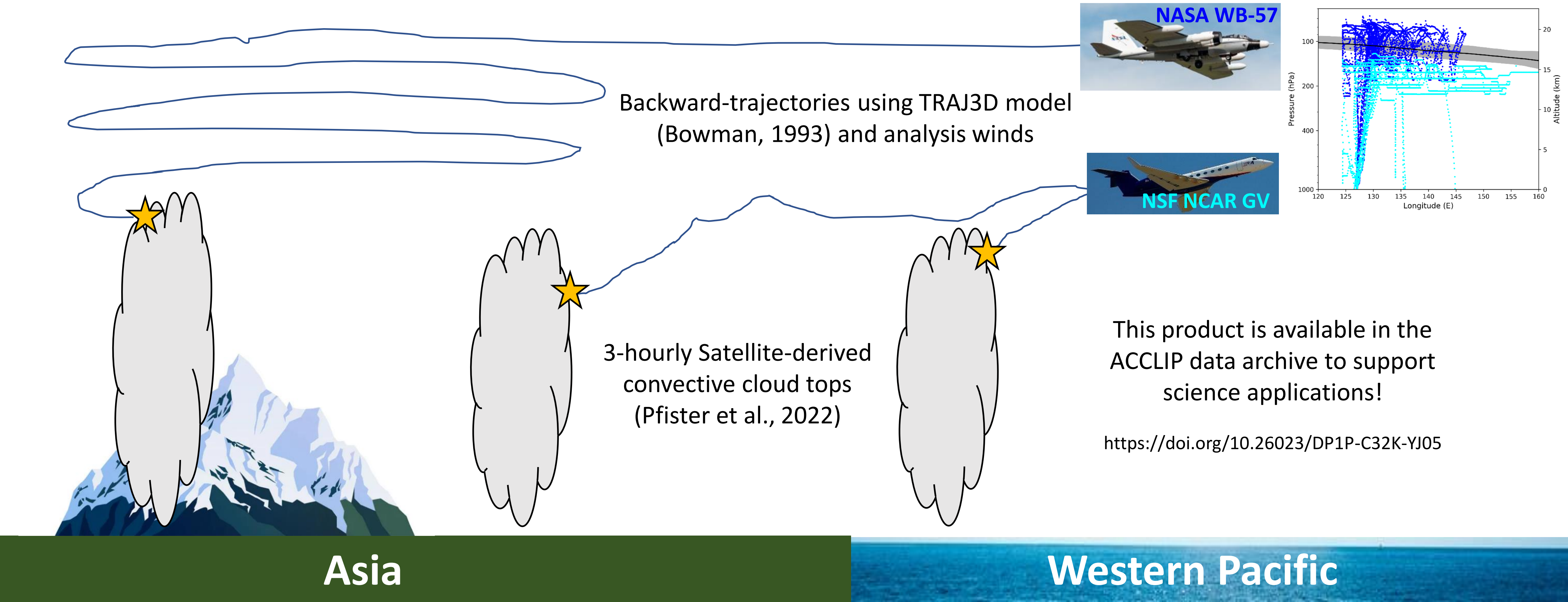


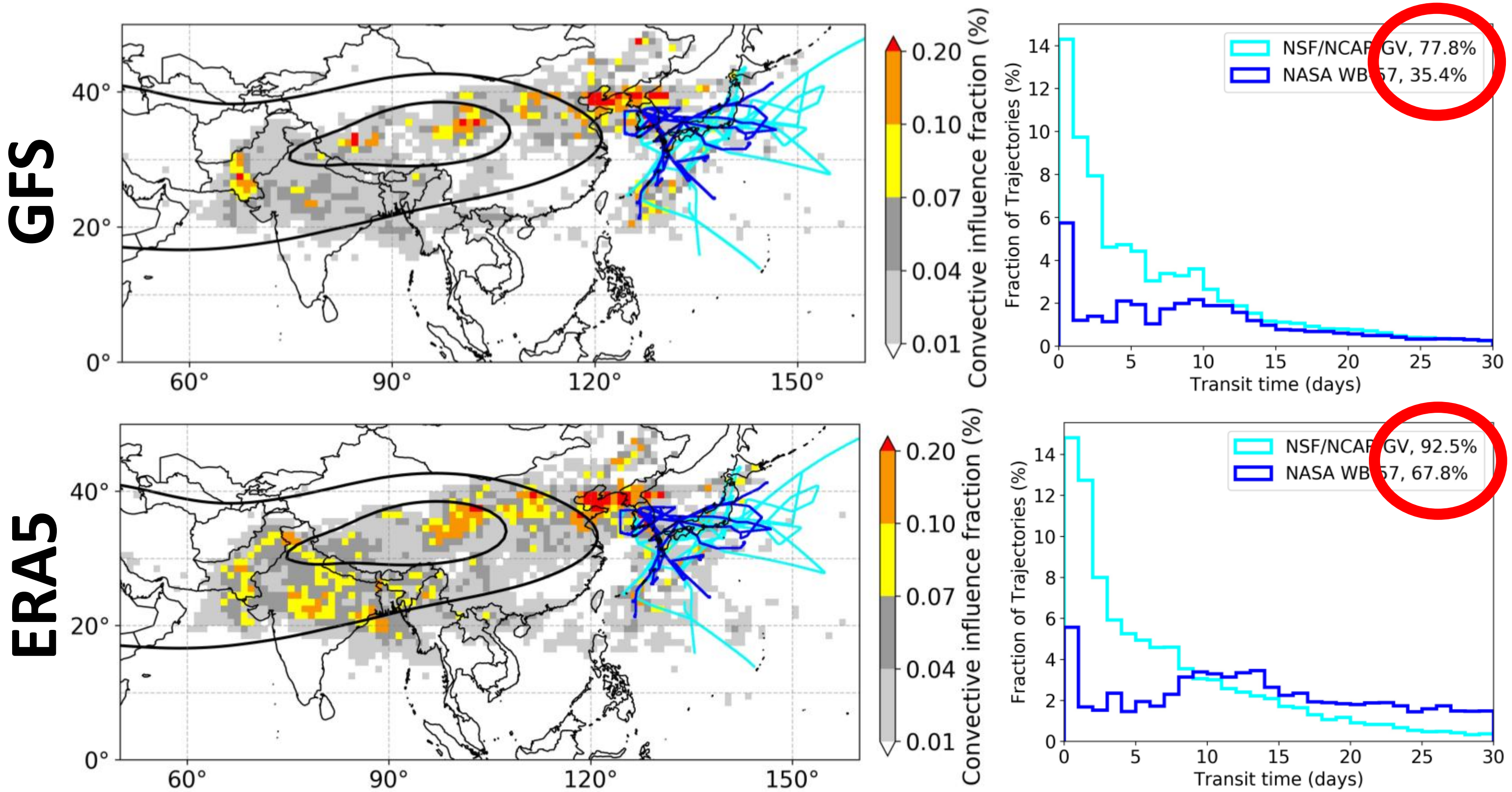
Figure courtesy of Pan et al. (2024)



Guiding Question: What pathway(s) did air travel from ASM convection to ACCLIP sampling?



Analysis winds used for trajectories give *qualitatively* similar, but *quantitatively* different solutions



There are two primary regions of convective contribution to ACCLIP sampling:

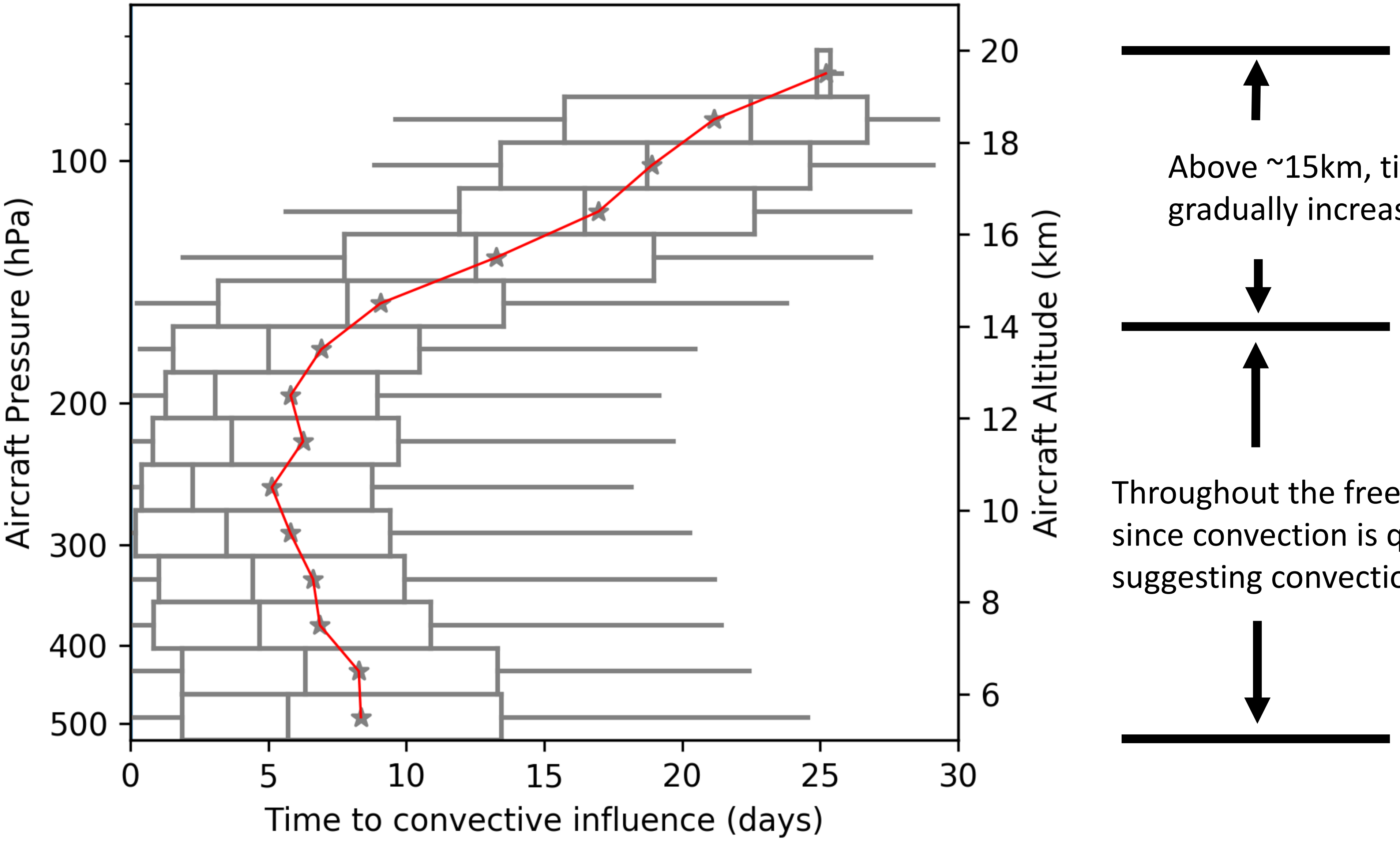
(1) Southern Asia / northern India and
(2) Along the east Asian subtropical front

The GV had considerably enhanced convective contribution and faster transport from convection compared to the WB-57, due to primary sampling altitudes

30-day convective influence percentages from GFS-kin are diminished compared to ERA5-kin, likely due to spatial and temporal resolution

ERA5-kin configuration is used hereafter

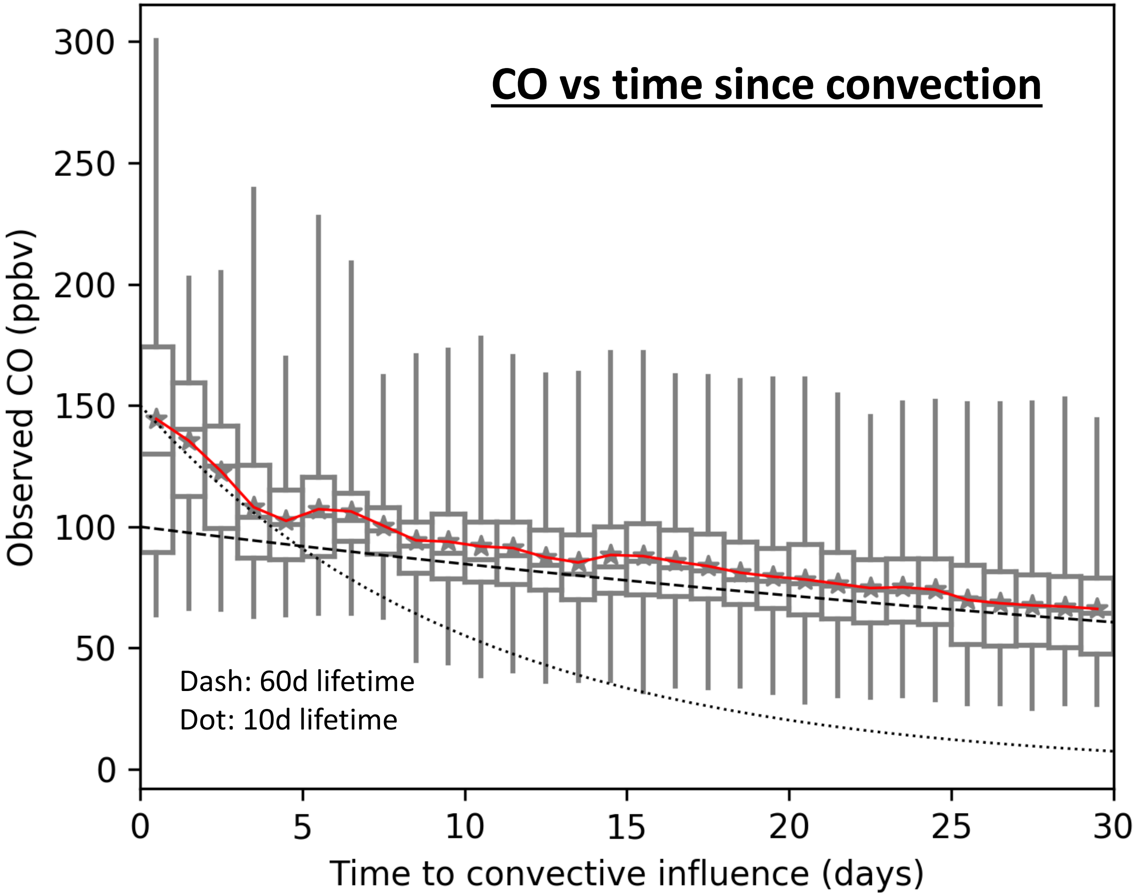
Time since convection as a function of aircraft sampling altitude



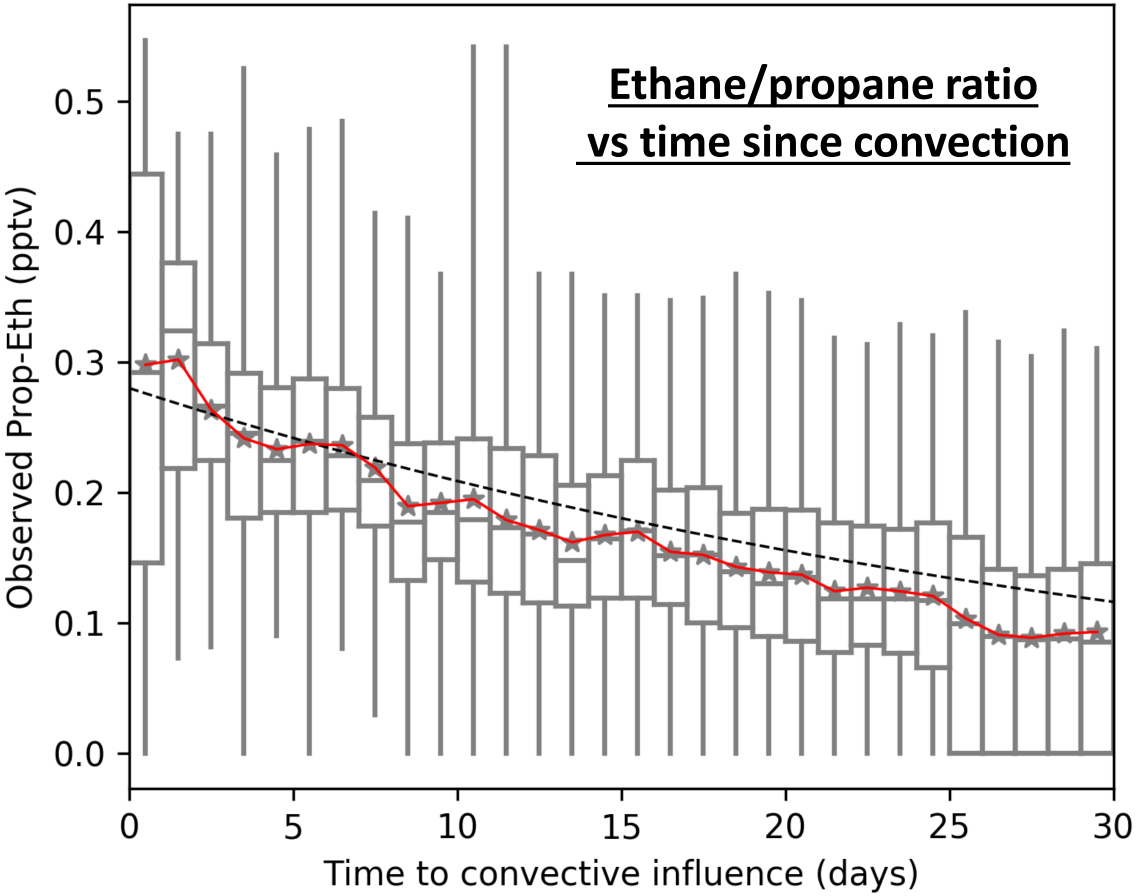
Above ~15km, time since convection gradually increases by ~5 days / km

Throughout the free troposphere, mean time since convection is quasi-constant (~a week), suggesting convection dominates in this layer

Trajectory-based convective influence is consistent with airborne sampling

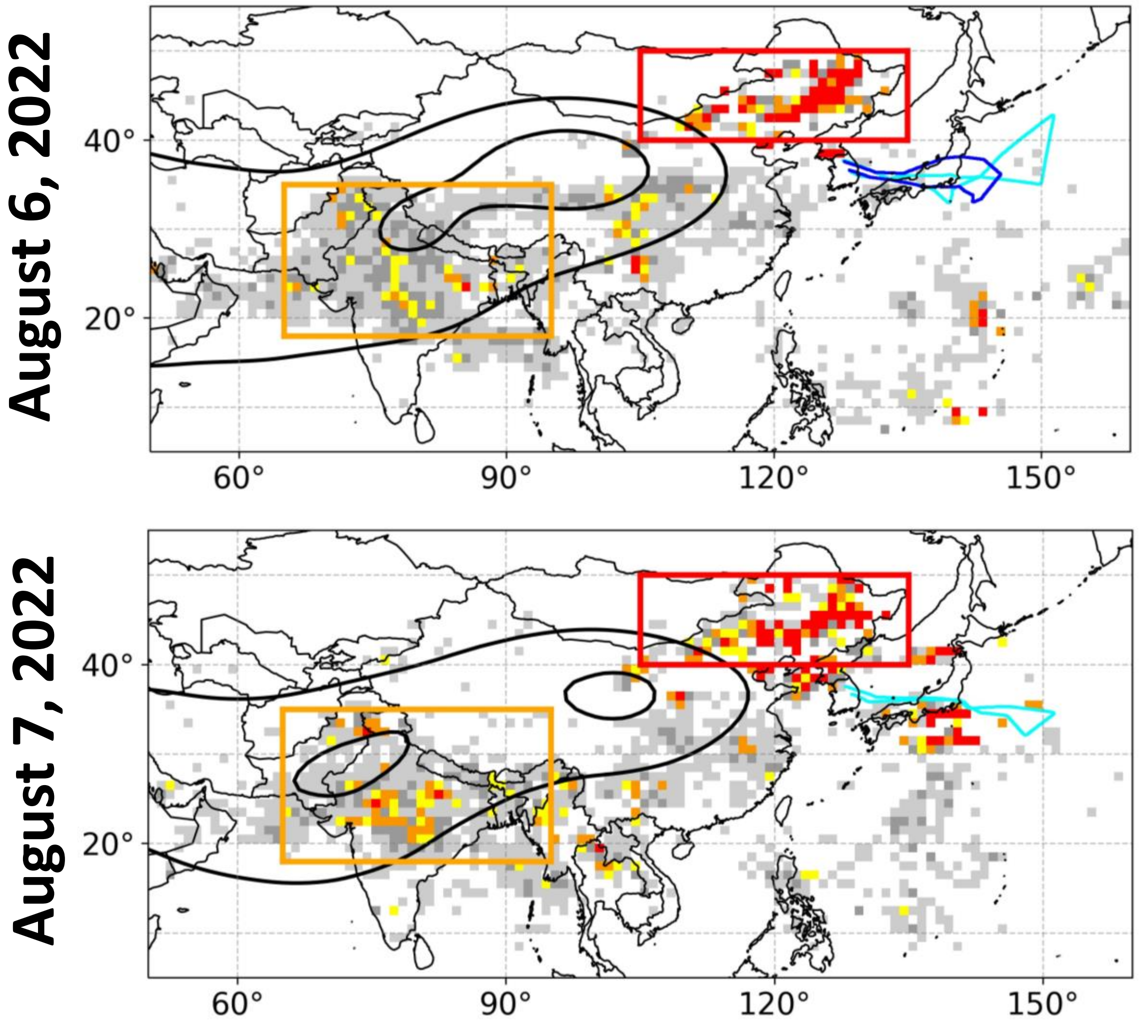


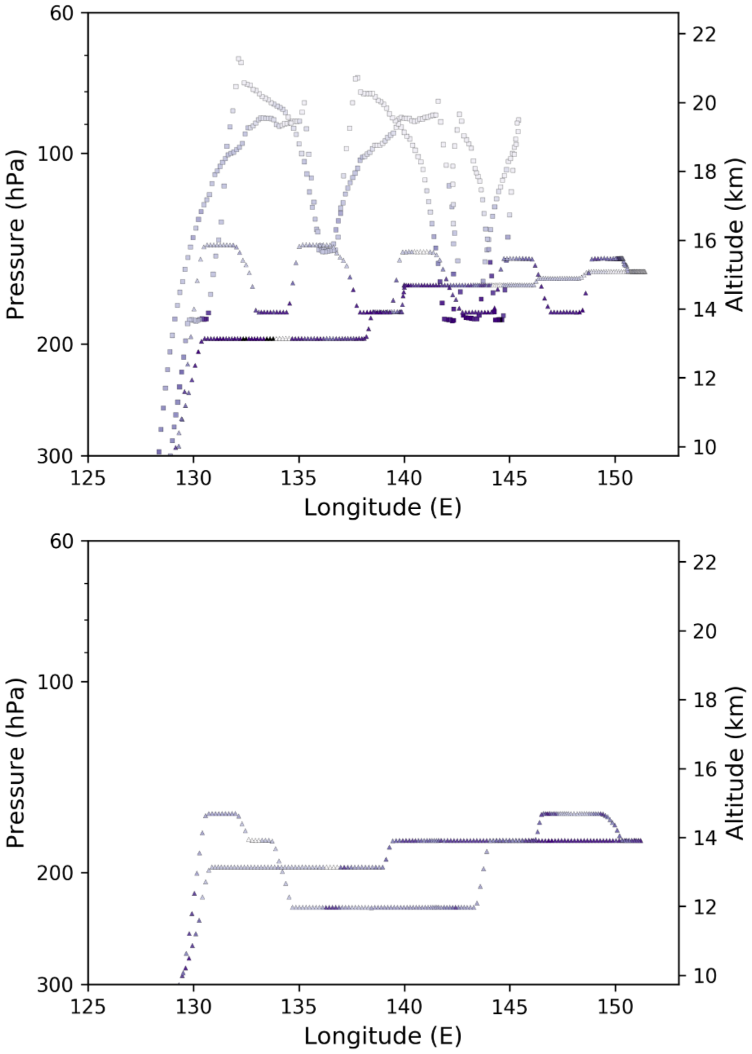
- The unprecedented pollution mixing ratios are all associated with very fresh convective outflow
- CO is lost rapidly within the first few days, but follows expected 60-day lifetime after ~ one week

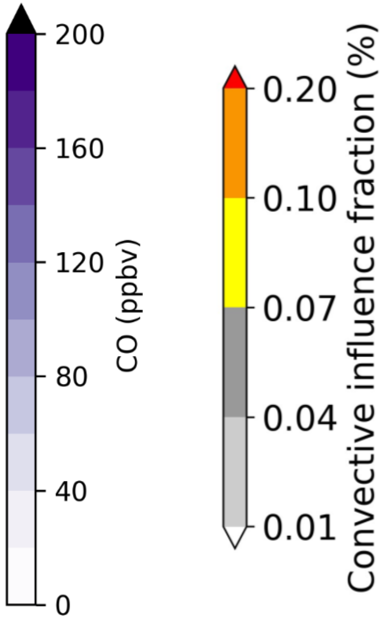


Trajectory-based time since convection is generally consistent with a hydrocarbon "clock" calculation (propane-ethane ratio shown here)

Flights on Aug 6-7, 2022 sampled horizontal, vertical and temporal gradients

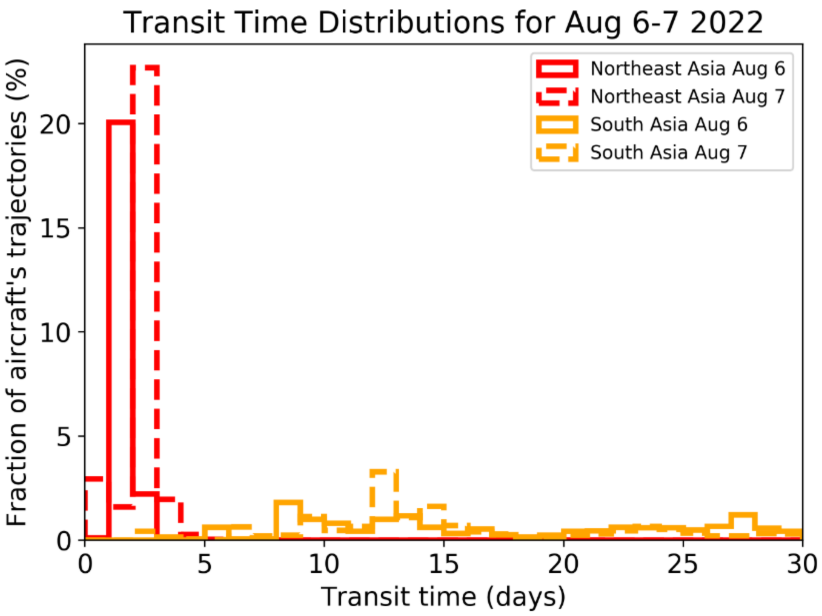


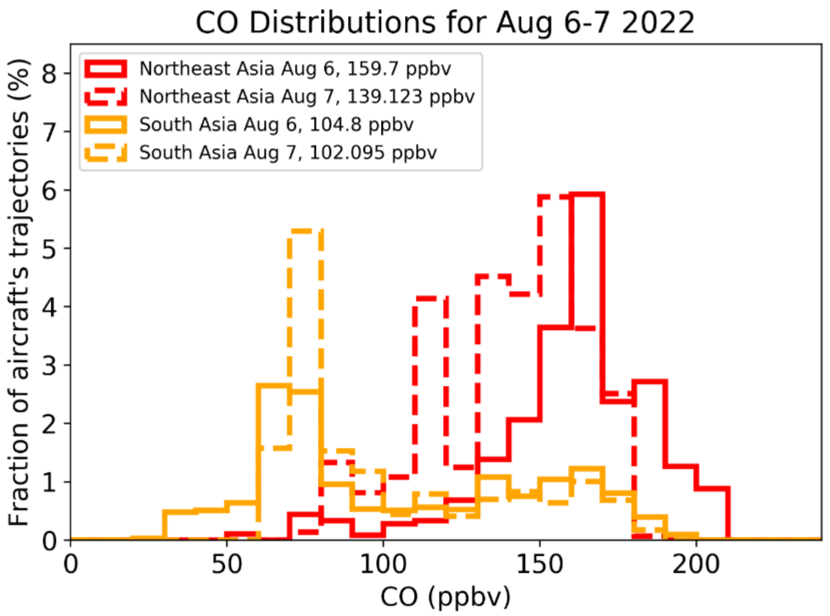


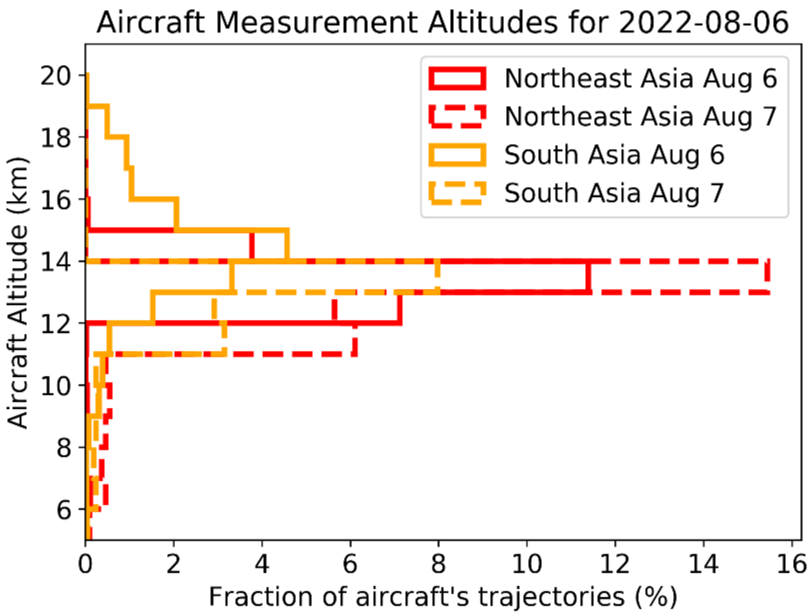


GV CO data provided by T. Campos, WB-57 CO data provided by S. Viciani and the COLD2 instrument team

Flights on Aug 6-7, 2022 sampled horizontal, vertical and temporal gradients







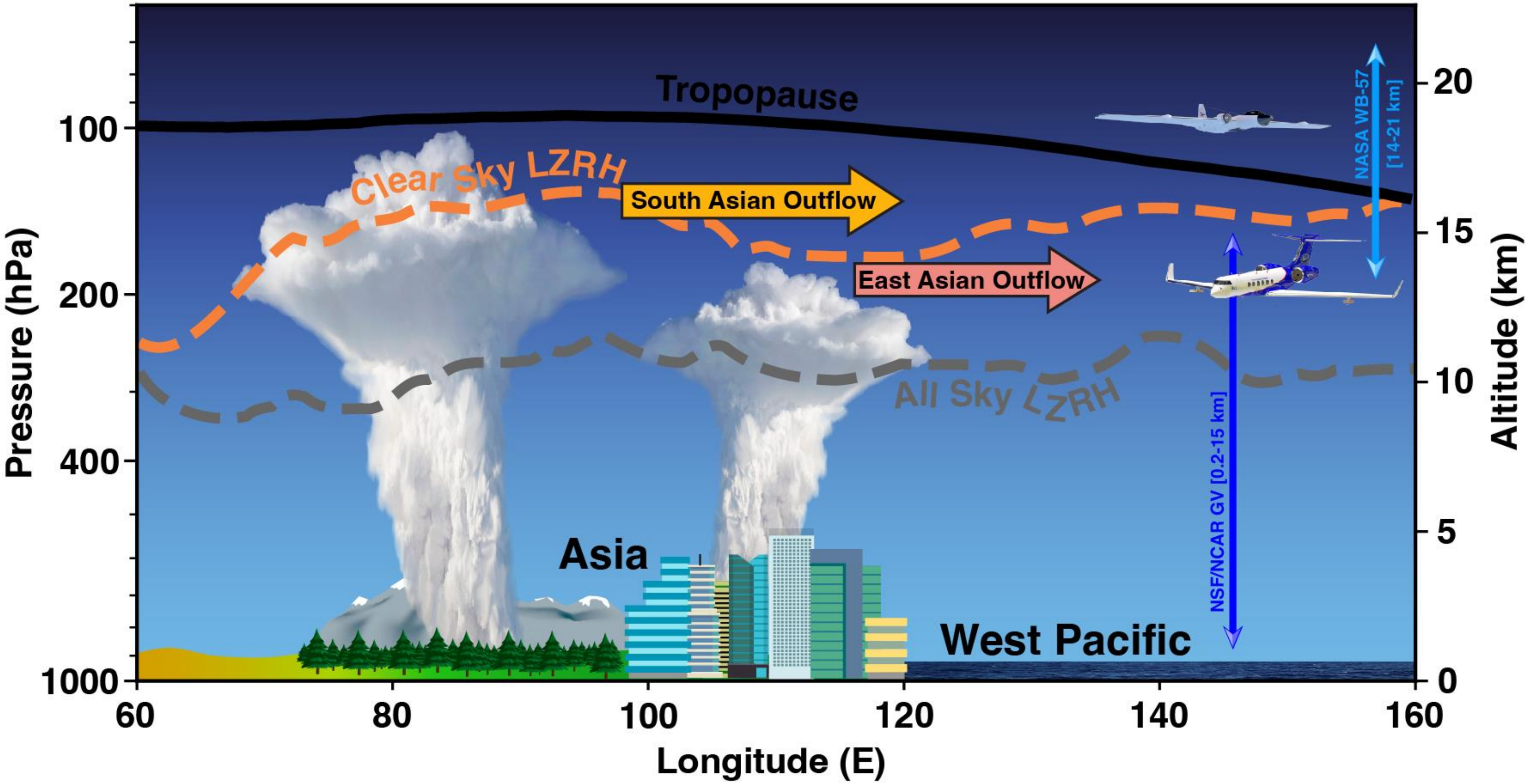
Northeast Asia was observed ~days since convection, while south Asia was ~weeks since convection

CO was considerably elevated in the "fresher" northeast Asia outflow

Northeast Asia CO attenuated considerably from Aug 6 to 7 sampling (~20 ppbv)

The northeast Asia source was only observed from 11-15 km aircraft altitude. Above 15 km, sampling was limited to more distant south Asian outflow

For all ACCLIP sampling, high-altitude obs *generally* traveled through the UTLS anticyclone to reach the sampling domain. UT obs were often influenced recently by eastern Asia convection carrying potent pollution



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

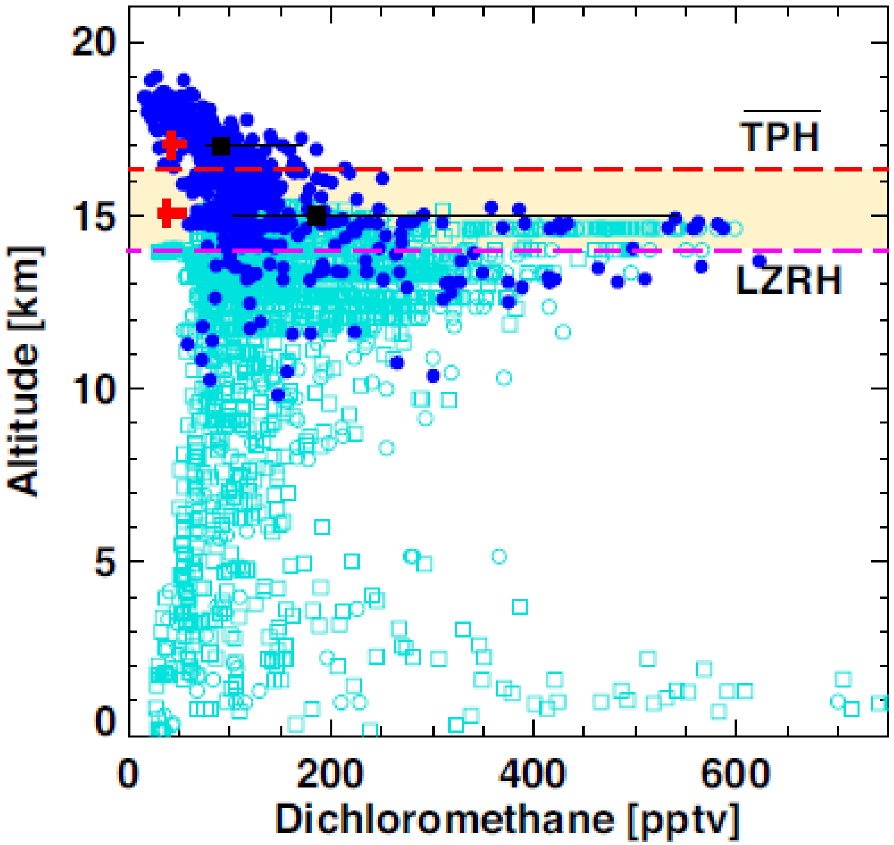
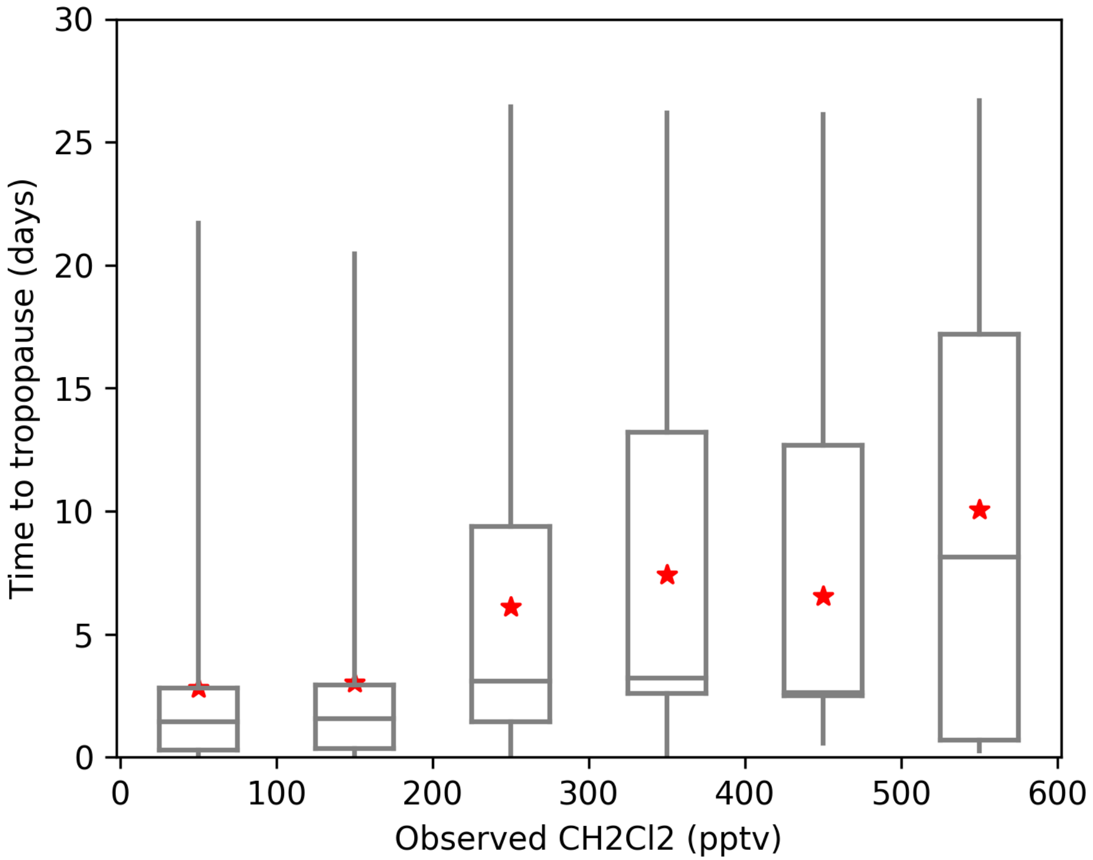


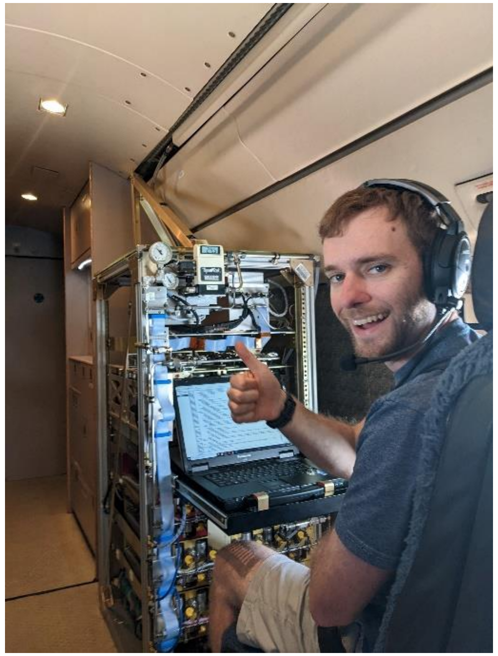
Figure courtesy of Pan et al. (2024)



Take-home messages

- The 2022 ACCLIP campaign has provided a unique dataset to investigate the role of the Asian monsoon in impacting global composition and climate
- Deep convective outflow from two monsoon sub-systems primarily contributed to ACCLIP sampling
  - The East Asian subtropical front – with enhanced pollution in “fresh” outflow
  - The South Asian monsoon – which may initially reach higher altitude than the EASF
- The impact of ASM convection on UTLS composition may be underestimated by satellite observations and coarse-grid global models
- Transport statistics can provide valuable context for airborne measurements!
  - Note that science applications likely benefit from analysis winds with high spatial resolution and temporal availability (e.g., ERA5)

Acknowledgements



ACCLIP was sponsored by NSF, NASA, NOAA, and NRL

Dr. Smith acknowledges funding from NSF and NASA, as well as support from the entire ACCLIP science team

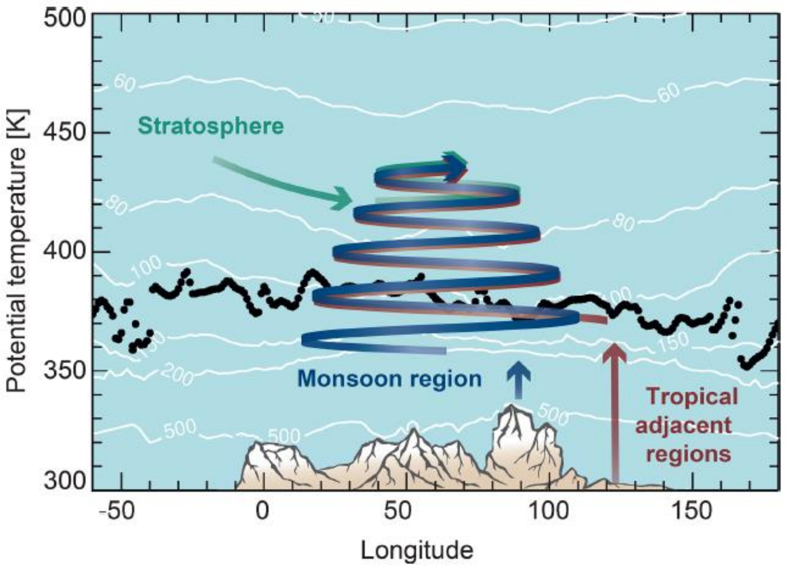
Thanks to the STIPMEX organizers for the invitation!

ACCLIP science highlight paper by Laura Pan et al. (2024): https://doi.org/10.1073/pnas.2318716121

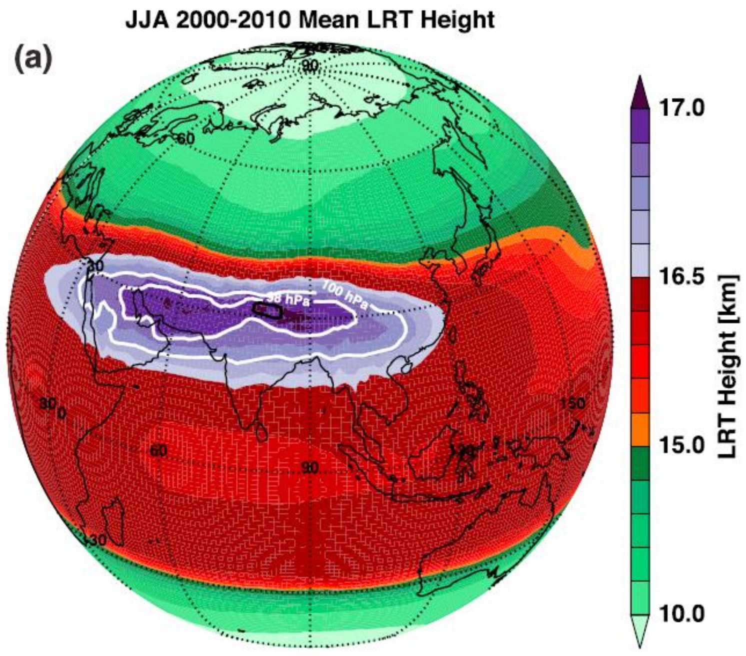
Thank you!!!

Extra Slides

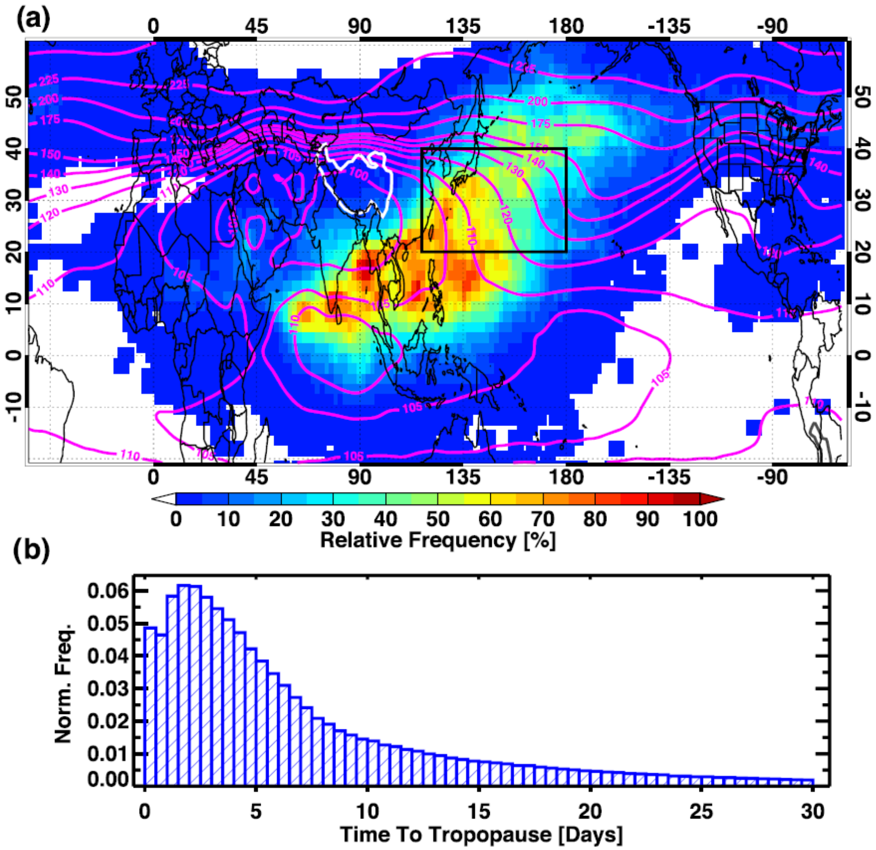
Air masses lofted by ASM convection have a pathway to reach the stratosphere



Vogel et al. (2019)



Pan et al. (2016)



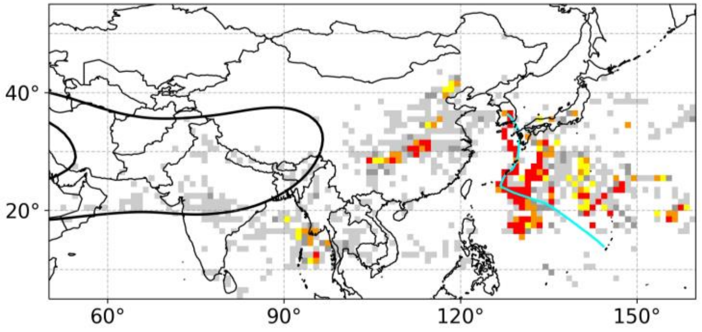
Honomichl and Pan (2020)

ACCLIP Airborne Measurements

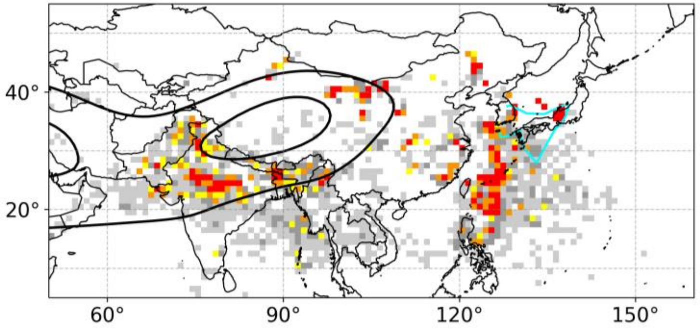
Measurement	WB	GV
State Parameters		
Position, Pressure, Temperature, Winds, Humidity	Aircraft, MMS	Aircraft, VCSEL
Temperature profile (above/below aircraft)		MTP
Trace Gases		
CO	COMA, COLD2, ACOS	Aerodyne, Picarro
CO_2	ACOS	Picarro
CH_4		Picarro
N_2O	COMA	Aerodyne
O_3	UAS O3	FAST_O3
NO, NO_2	NO-LIF	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

Trajectory-derived convective influence provides context for understanding specific flights

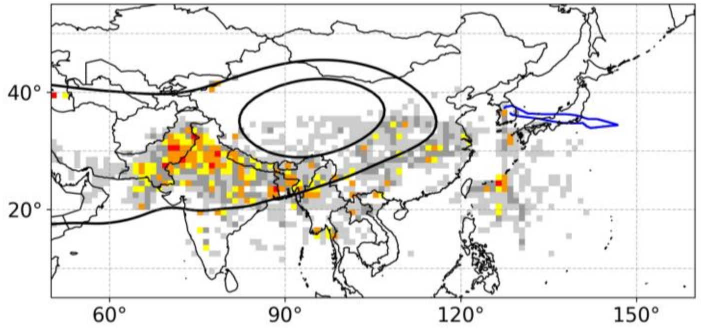
GV July 31, 2022
Western Pacific



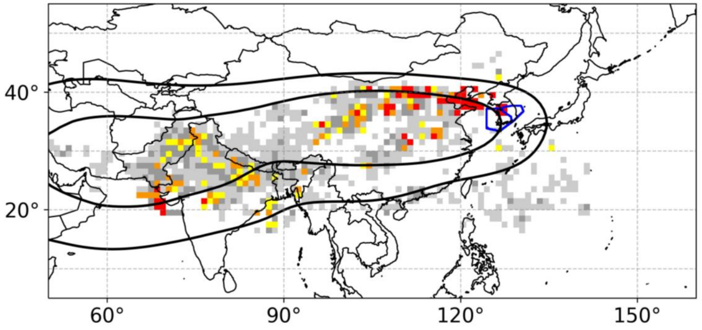
GV August 4, 2022
Western Pacific & South Asia



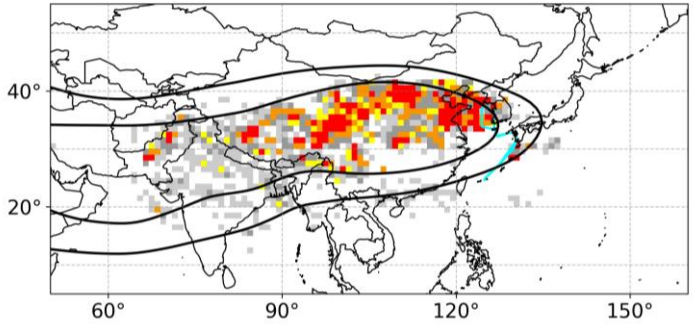
WB-57 August 12, 2022
South Asia



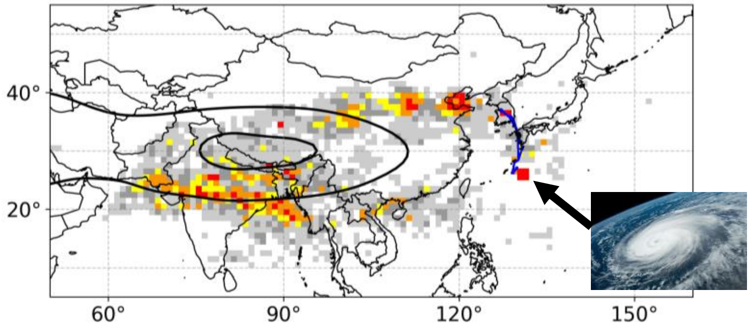
WB-57 August 19, 2022
East & South Asia

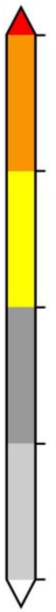


GV August 23, 2022
Central & Eastern China

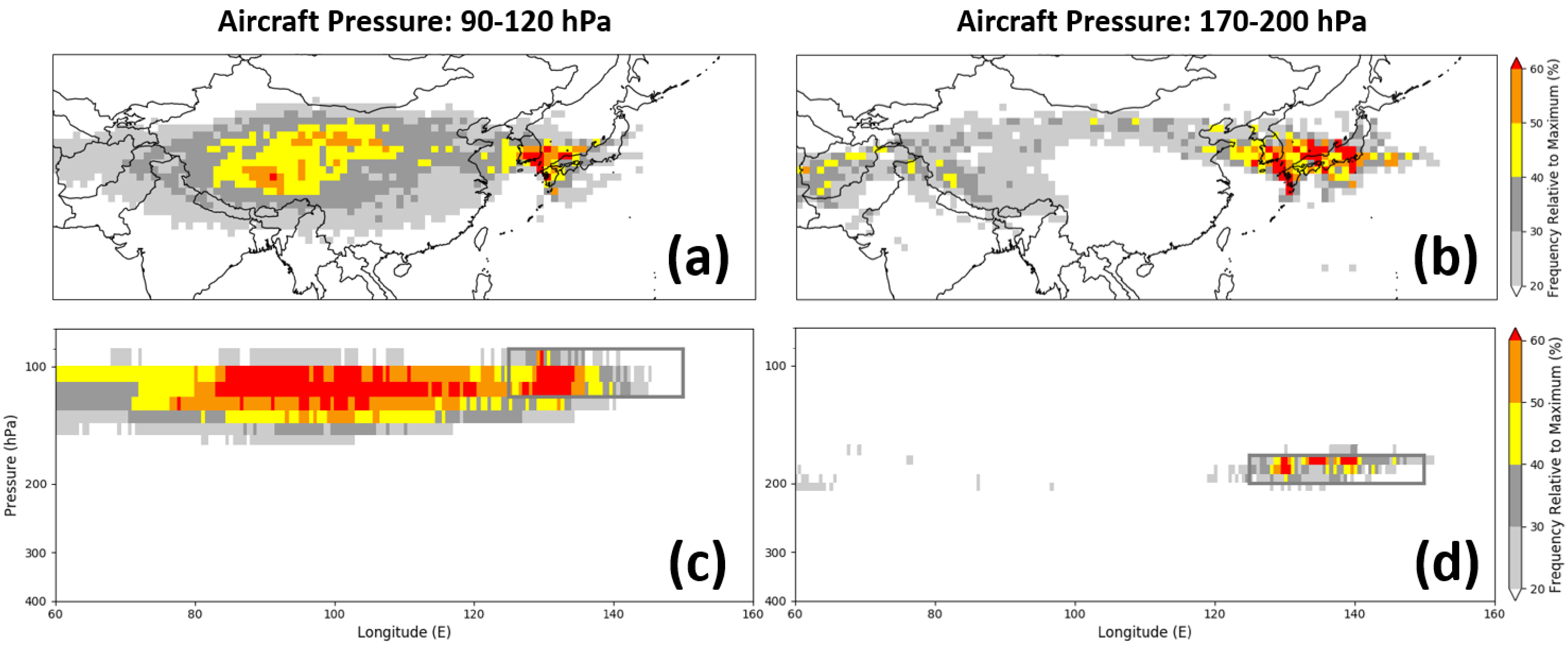


WB-57 August 31, 2022
E Asia & S Asia & Typhoon!

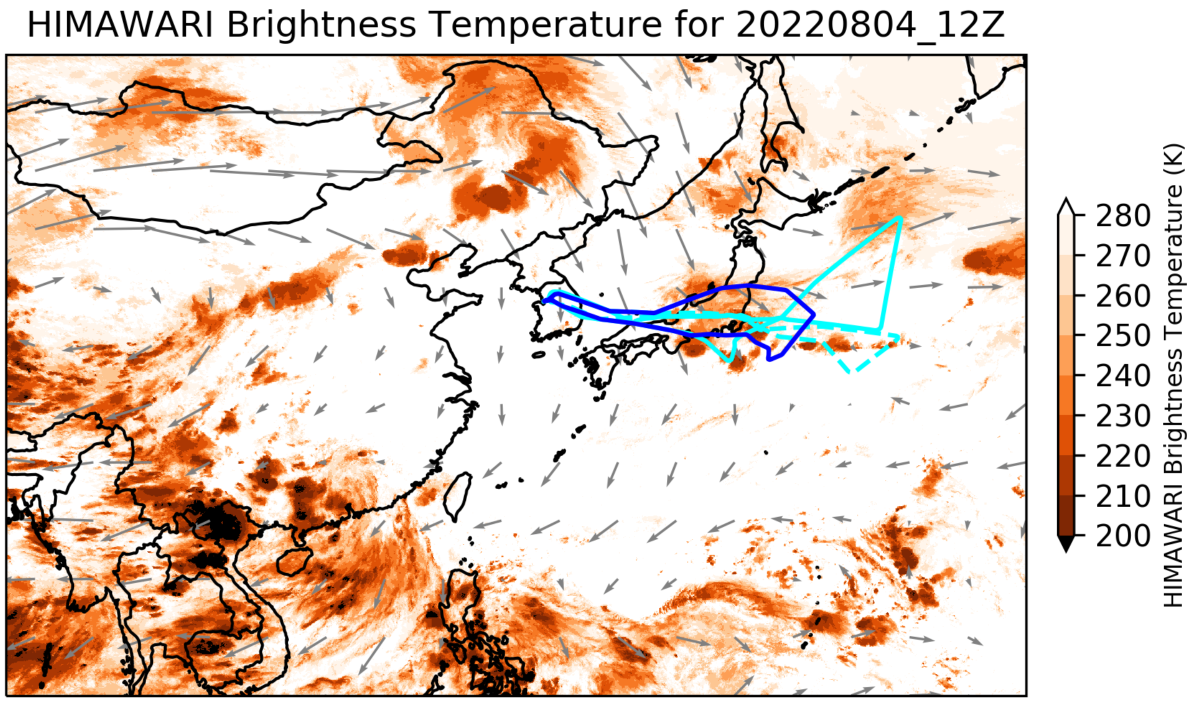


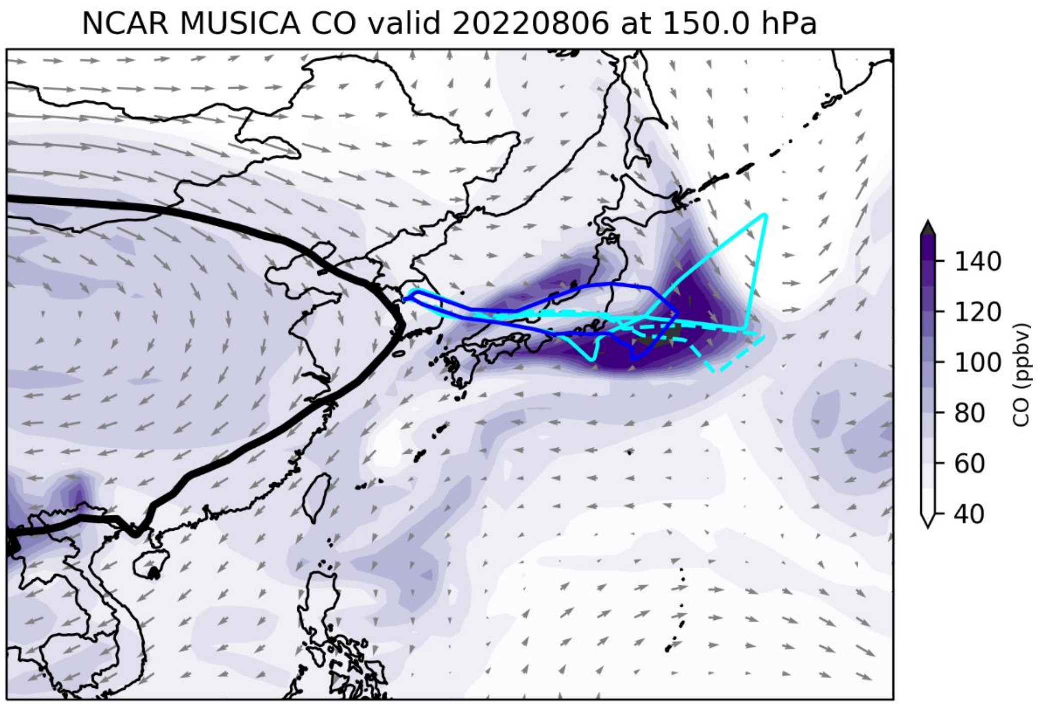


For all ACCLIP sampling, higher-altitude obs generally traveled through the UTLS anticyclone to reach the sampling domain. UT obs were often influenced recently by eastern Asia convection carrying potent pollution



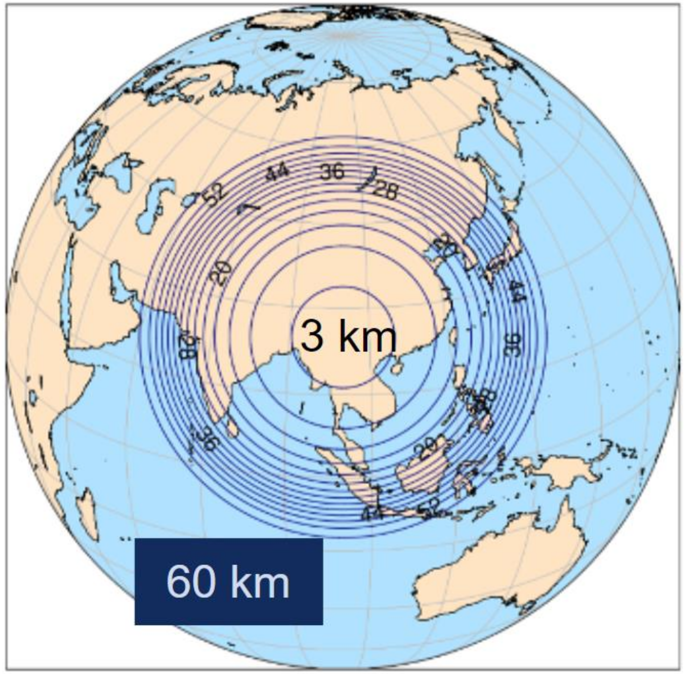
Flights on Aug 6-7, 2022 sampled horizontal, vertical and temporal gradients

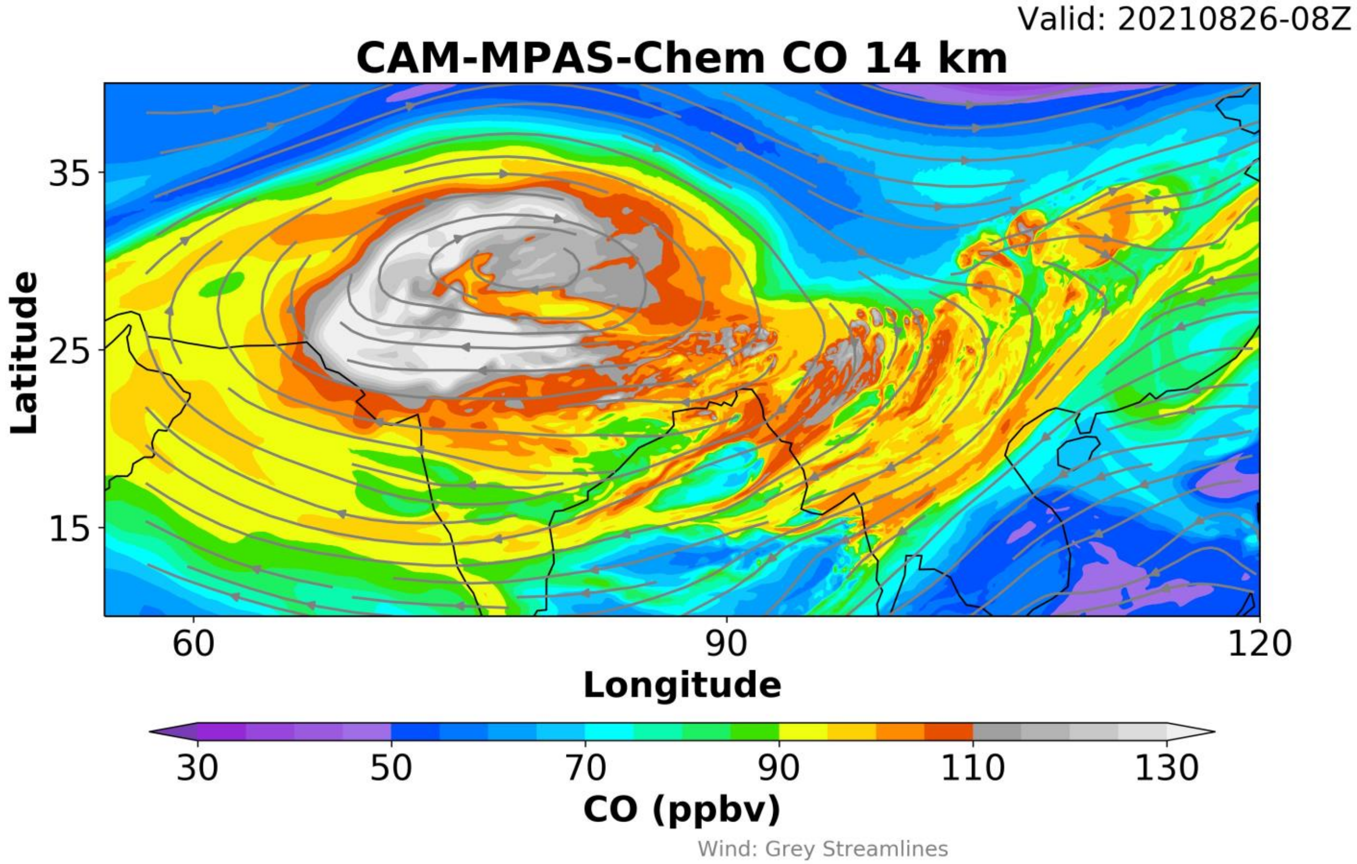




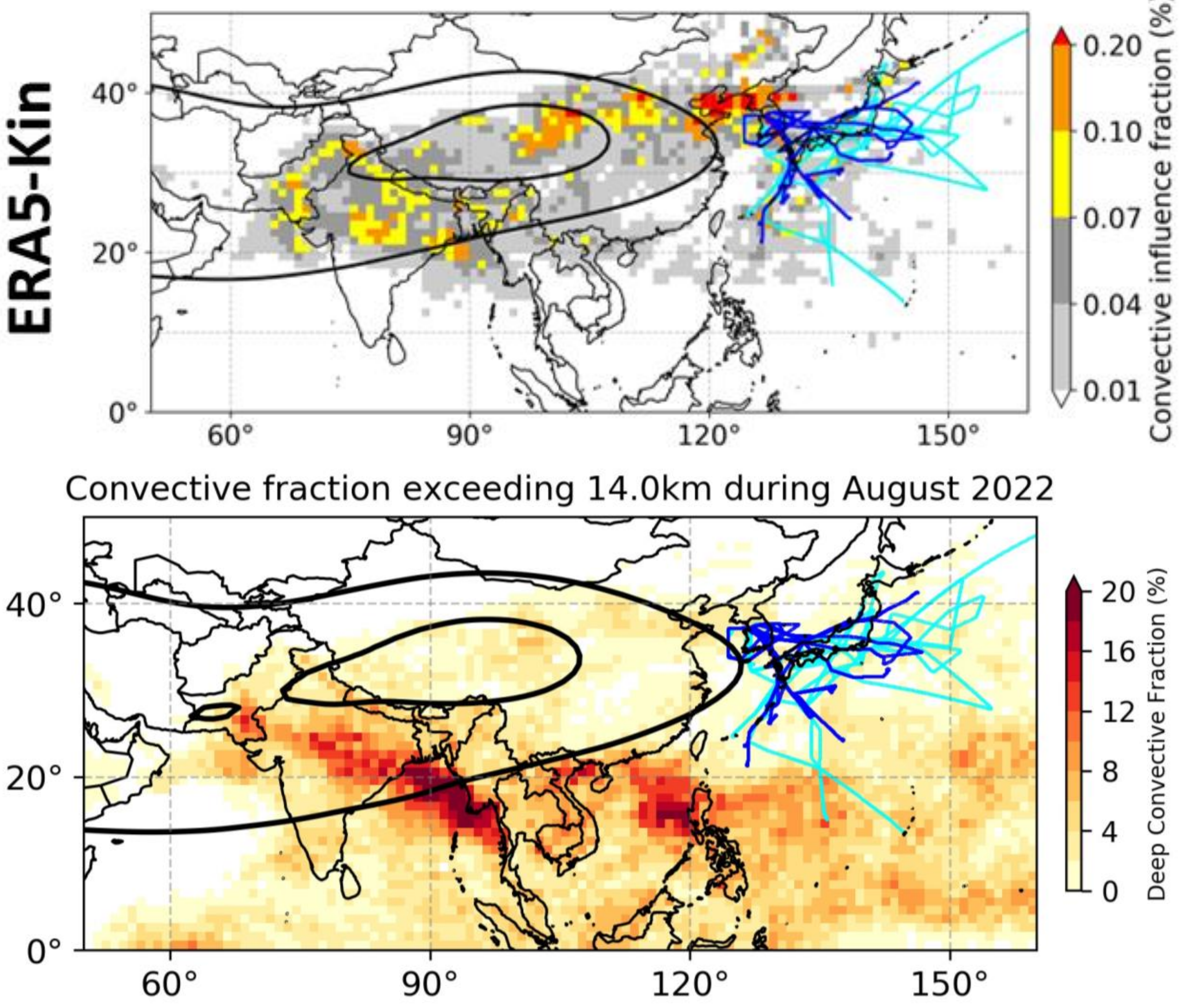
Wind vector level: 150 hPa

Multi-scale (non-hydrostatic) global models may offer better representation of transport when convection is an important process

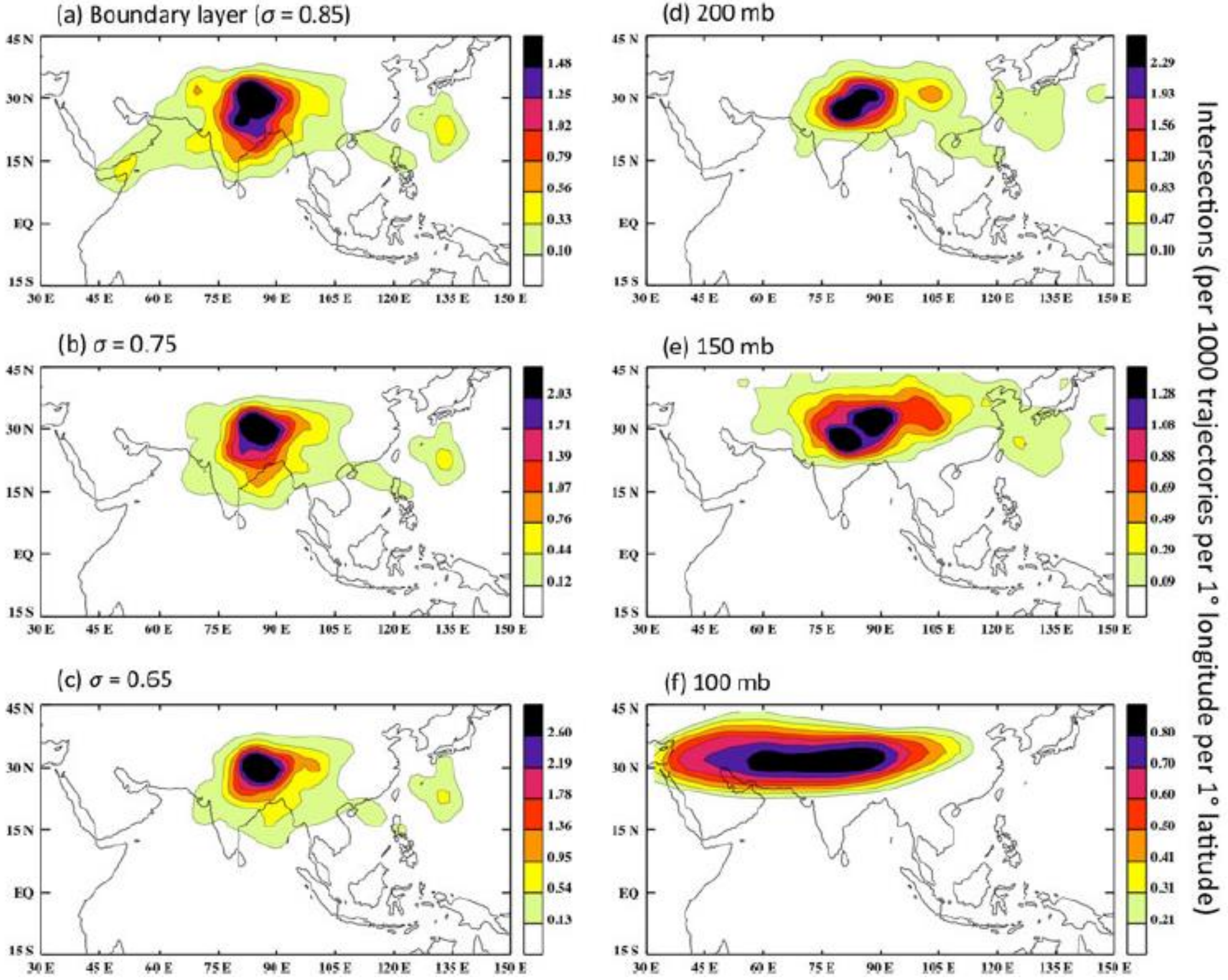




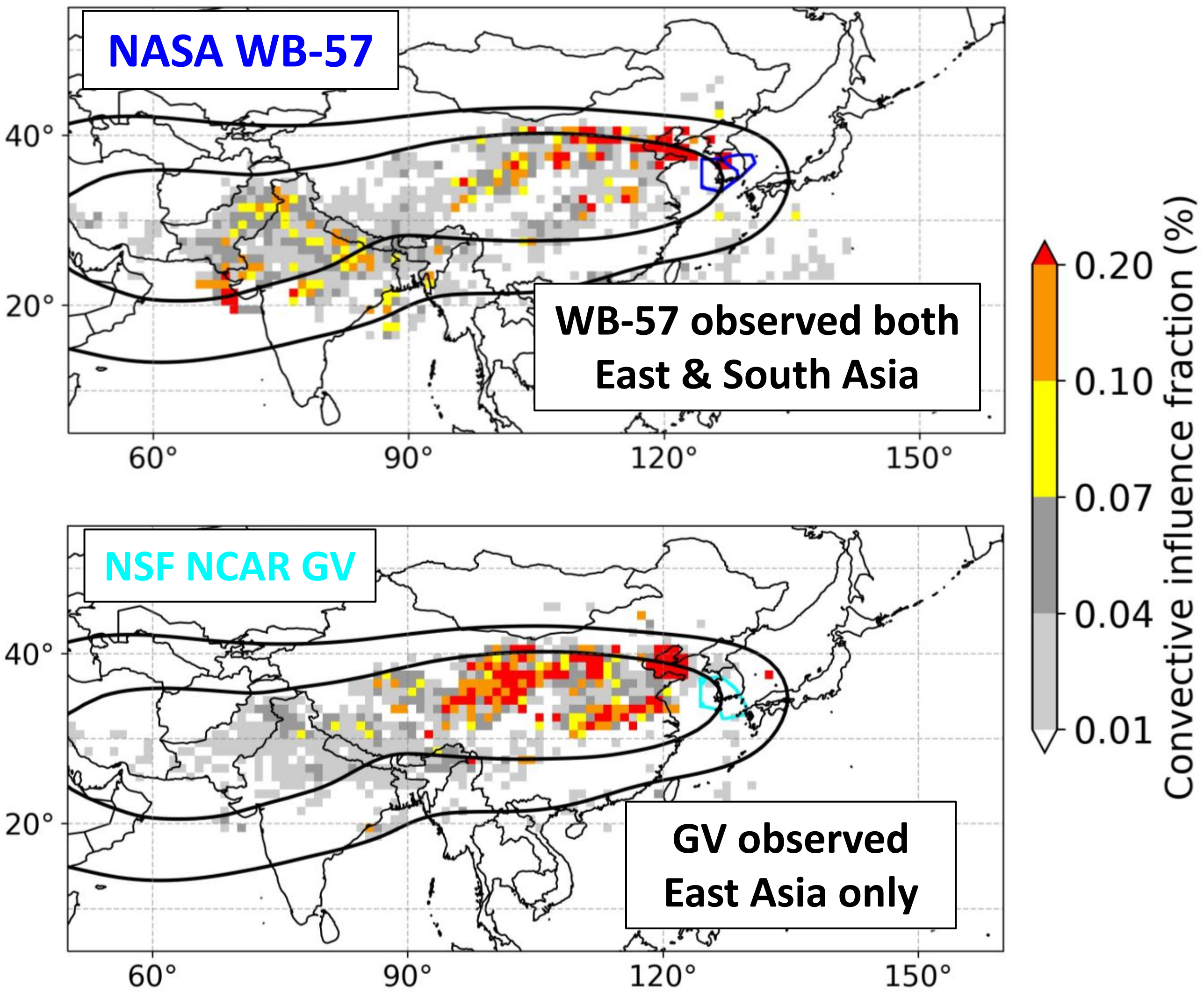
Collaboration with Mary Barth, Francis Vitt, Bill Skamarock at NSF NCAR

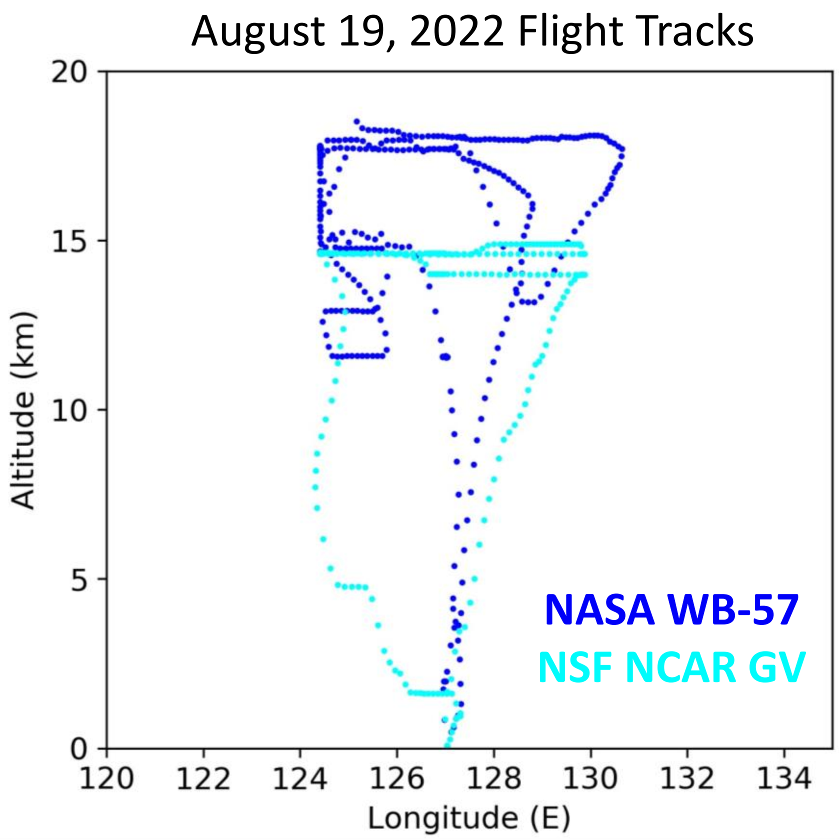


Trajectory intersections: 100 mb calculations



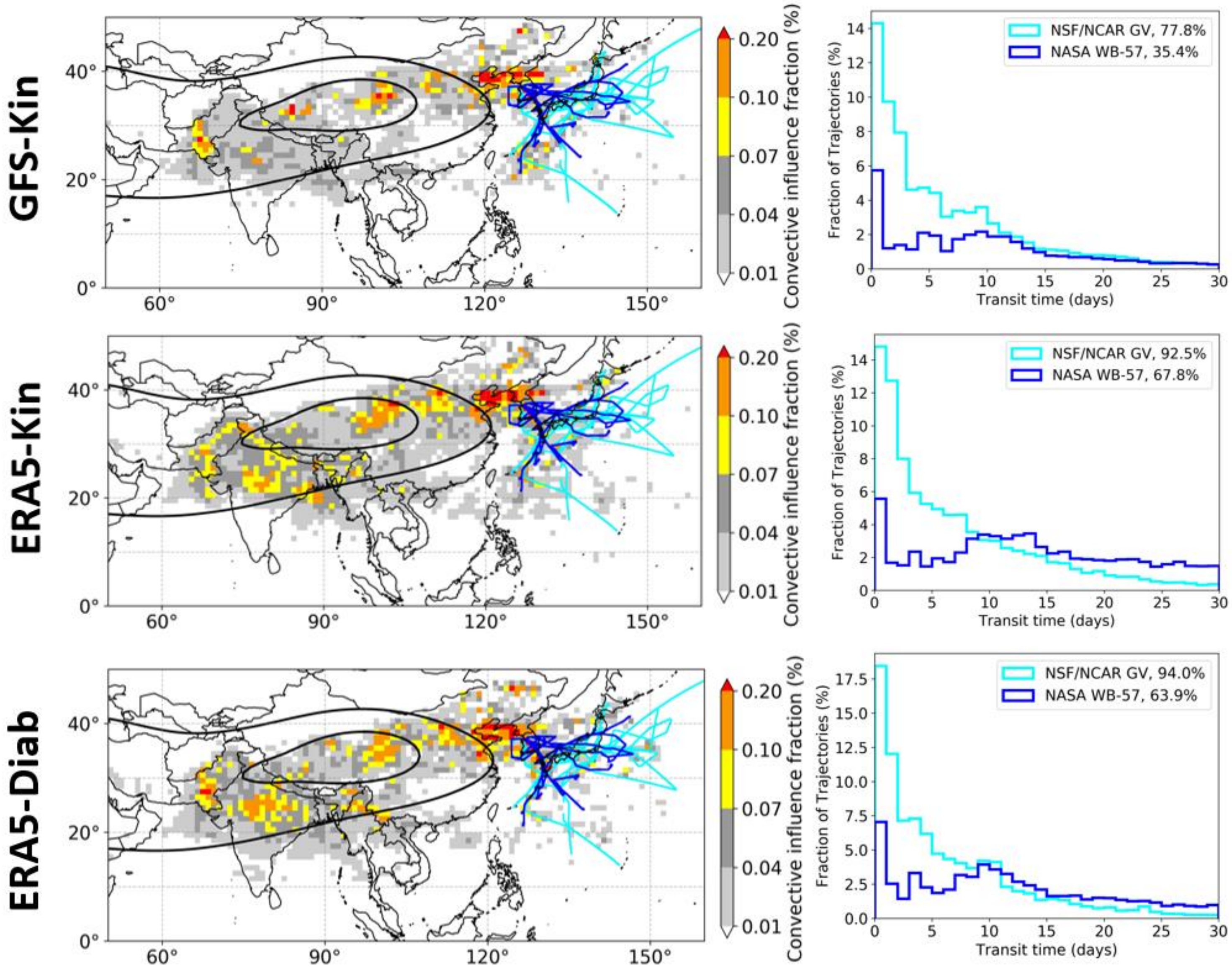
August 19, 2022: Aircraft observed different sampling regimes from the same area





The remote south Asian outflow was only observable above 15km altitude!

Analysis winds used for trajectories give *qualitatively* similar, but *quantitatively* different solutions



There are two primary regions of convective contribution to ACCLIP sampling: (1) southern Asia / northern India and (2) along the east Asian subtropical front

The GV had considerably enhanced convective contribution and faster transport from convection compared to the WB-57, due to primary sampling altitudes

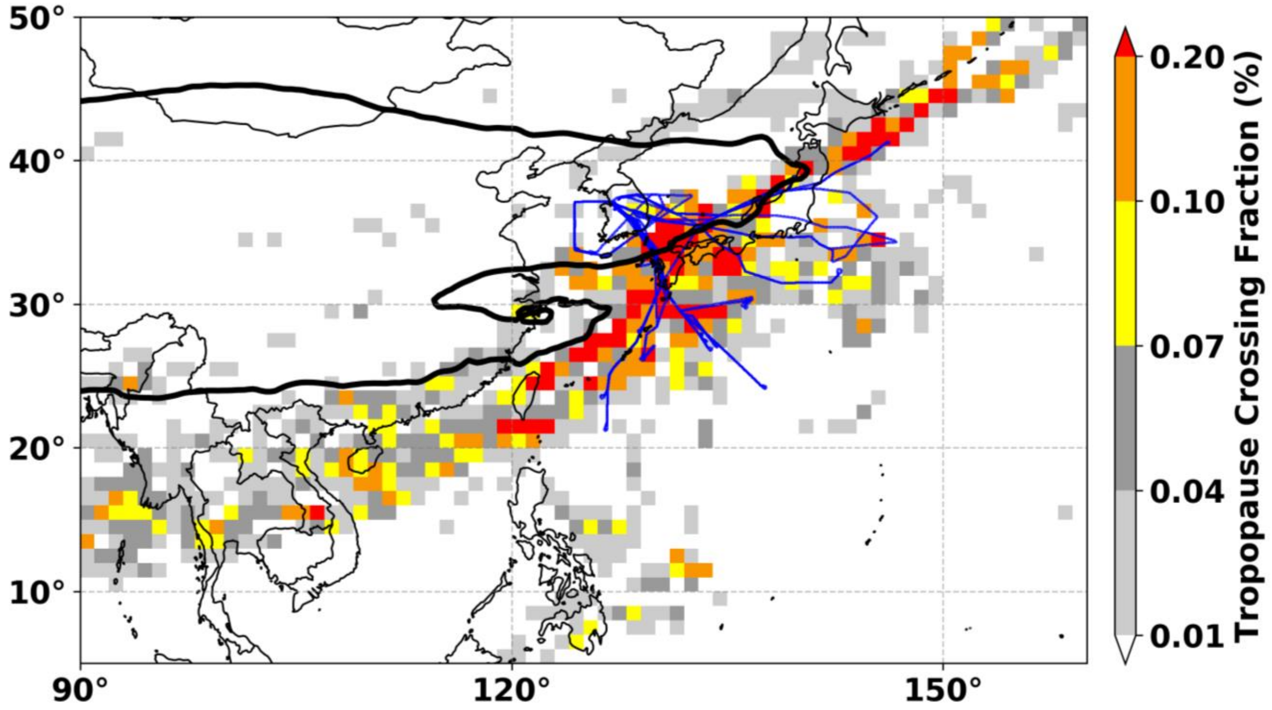
30-day convective influence percentages from GFS-kin are diminished compared to ERA5-kin, likely due to spatial and temporal resolution

ERA5-kin and ERA5-diab are similar, likely because we consider transport <u>to</u> convection but not *<u>through</u>* convection

ERA5-kin configuration is used hereafter

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

>85% of parcels between 360K and the tropopause reached the stratosphere within 20 days following sampling!!



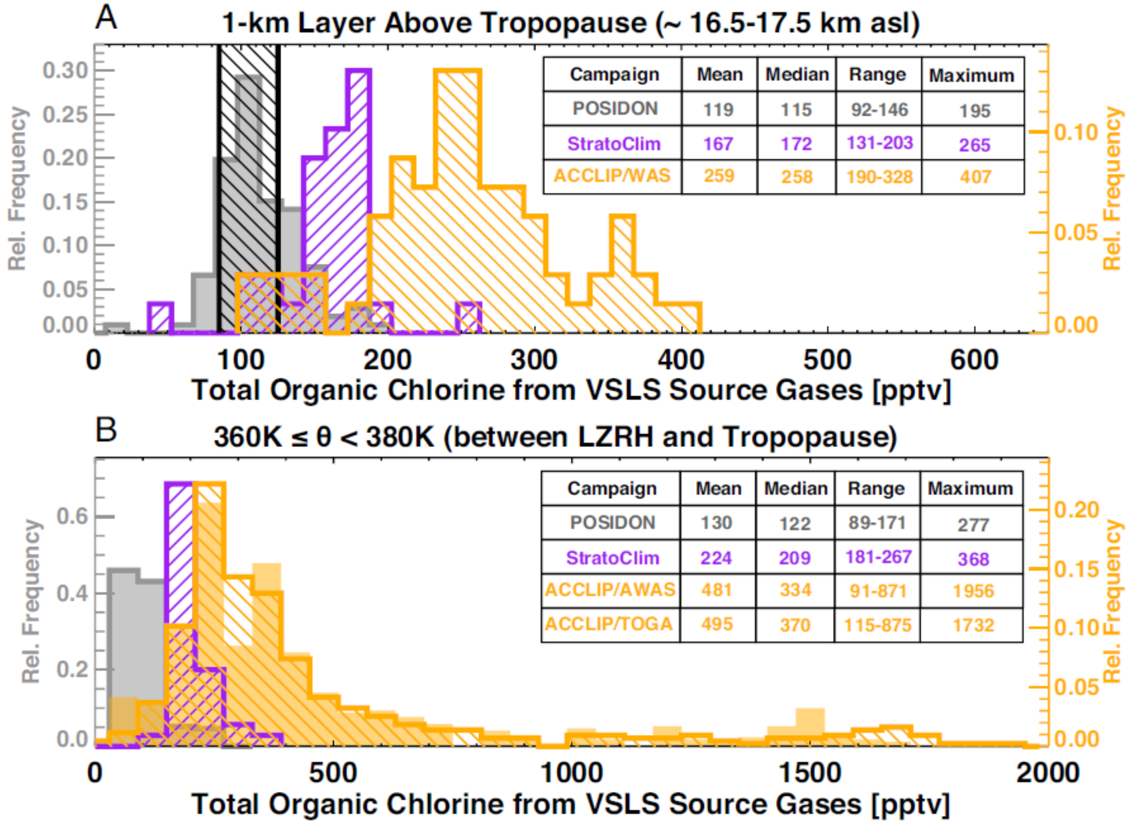


Figure courtesy of Pan et al. (2024)