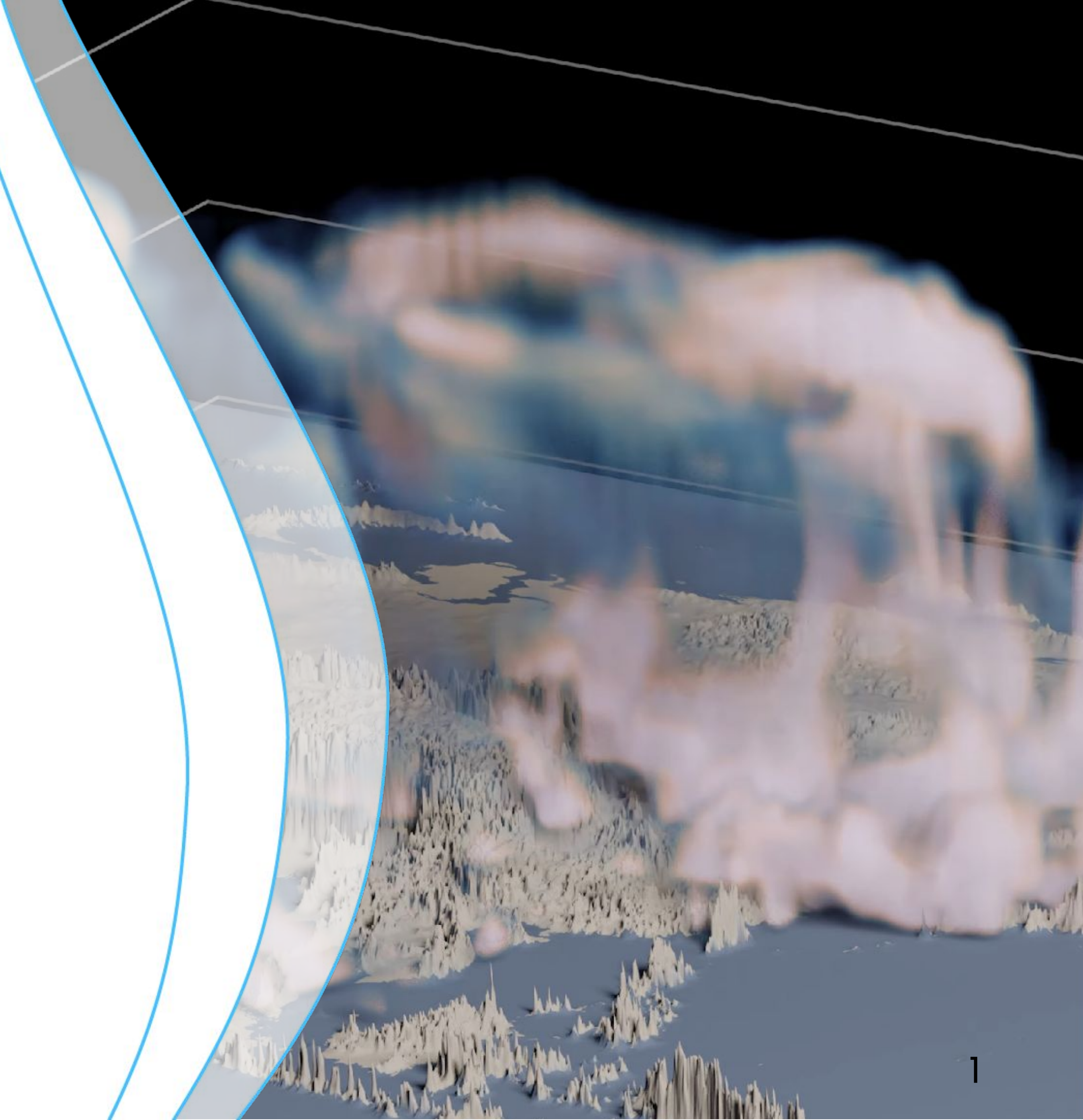
February 3, 2026
CESM Working Group Meeting

Deep Convective Transport in CAM-Chem is Sensitive to Nudging Analysis Choice

Ren Smith
NSF NCAR / ACOM

With collaboration from: Simone Tilmes, Ben Gaubert, Rich Neale, Mary Barth, Louisa Emmons, a great many others



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Approach

Goal: Investigate how convection responds to changes in (1) nudging analysis and (2) ZM-KE parameterization development*, and characterize the resulting impacts on composition

Sensitivity runs:

ERA5 / ZM | ERA5 / ZM-KE | MERRA-2 / ZM | MERRA-2 / ZM-KE

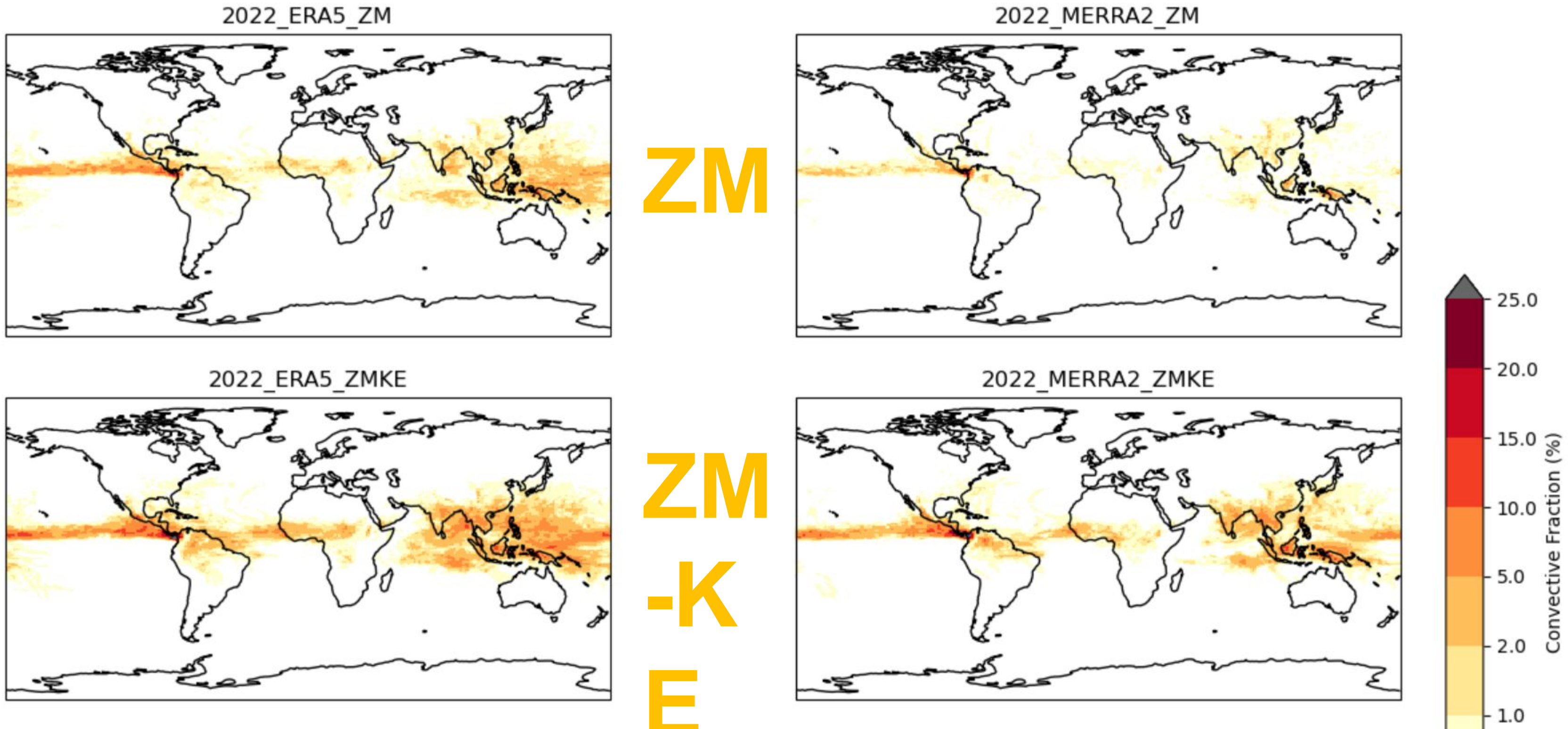
Model configuration:

CESM2 / CAM-Chem, One-degree FV, 32 vertical levels, CAMS-MOSAIC emissions, Posterior CO emissions**, MAM4 aerosol

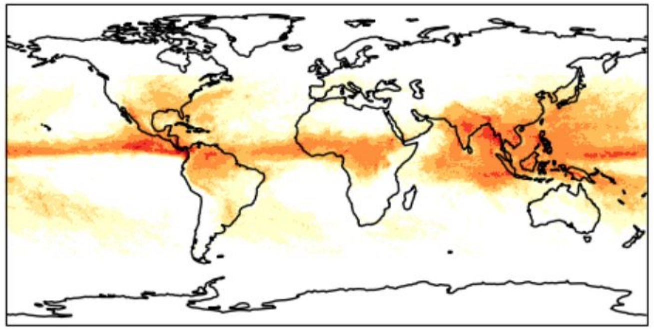
* Developed by Rich Neale

** Courtesy of Ben Gaubert

ERA5 MERRA-2



Cloud top observations from CloudSat / TRMM courtesy of Rei Ueyama (NASA)



Obs

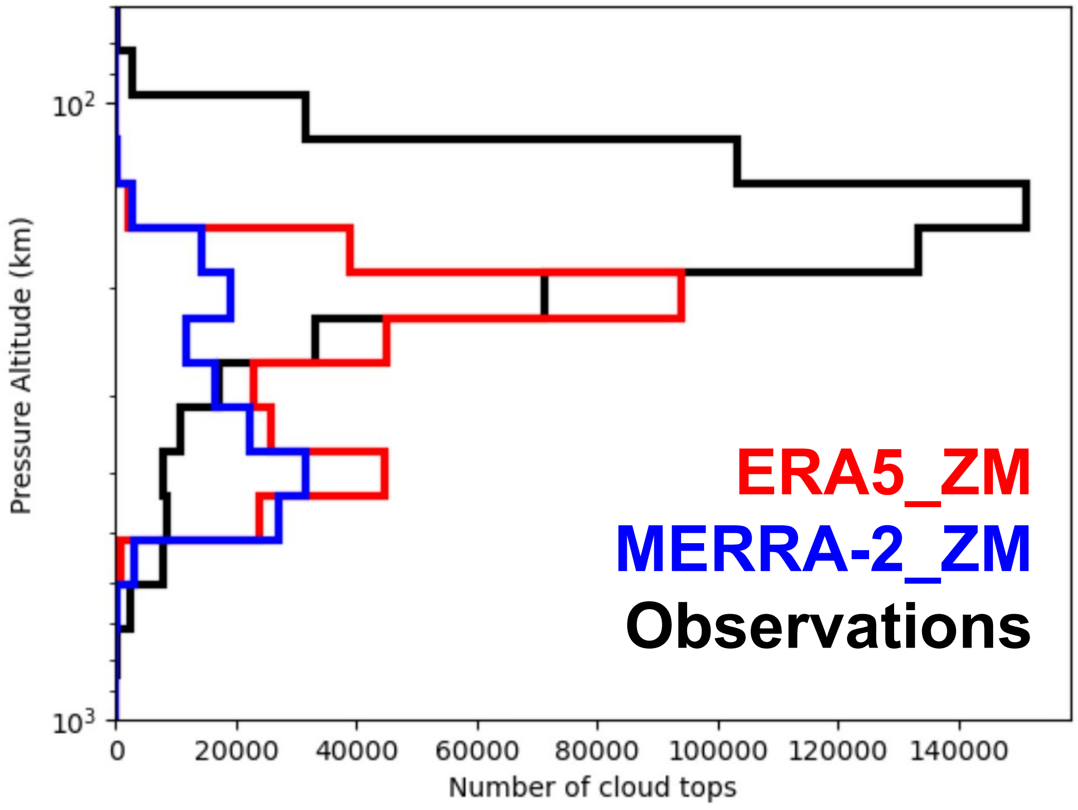
Deep convection above 200 hPa, convective precip > 1.0 mm/hr, valid May-Sept 2022

Deep convective fraction increases and improves vs obs with:

- Nudging toward ERA5
- ZM-KE modifications

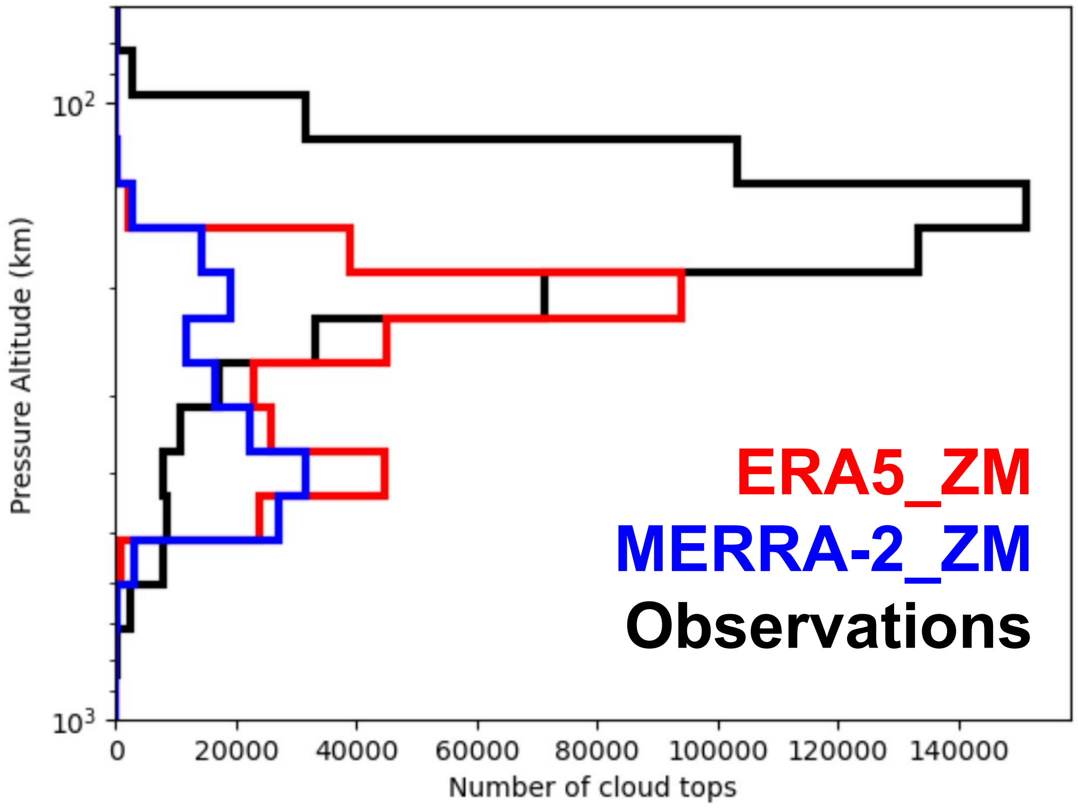
Nudging toward ERA5 increases the depth of convection, improving representation with obs

20S-20N Cloud Top Comparison for May-Sept

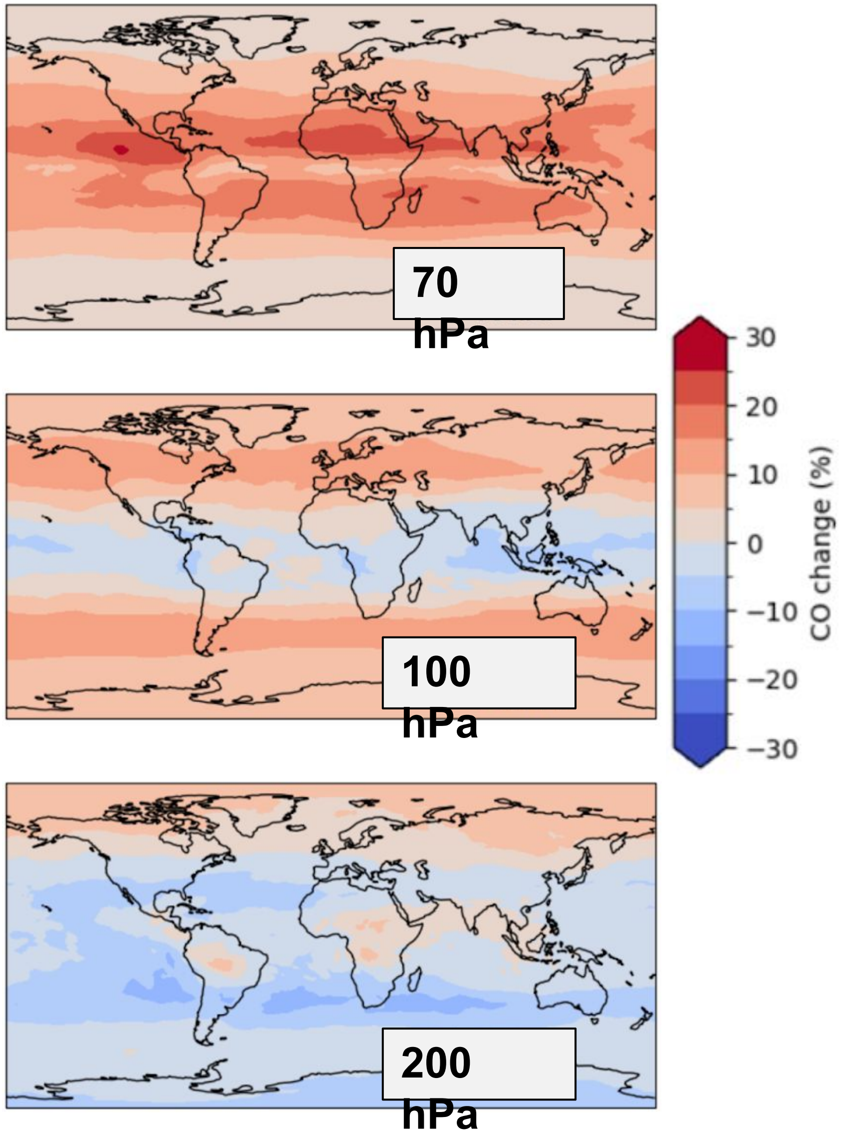


Cloud top observations from CloudSat / TRMM courtesy of Rei Ueyama (NASA)

Nudging toward ERA5 increases CO transport to the lower stratosphere by ~10-20%

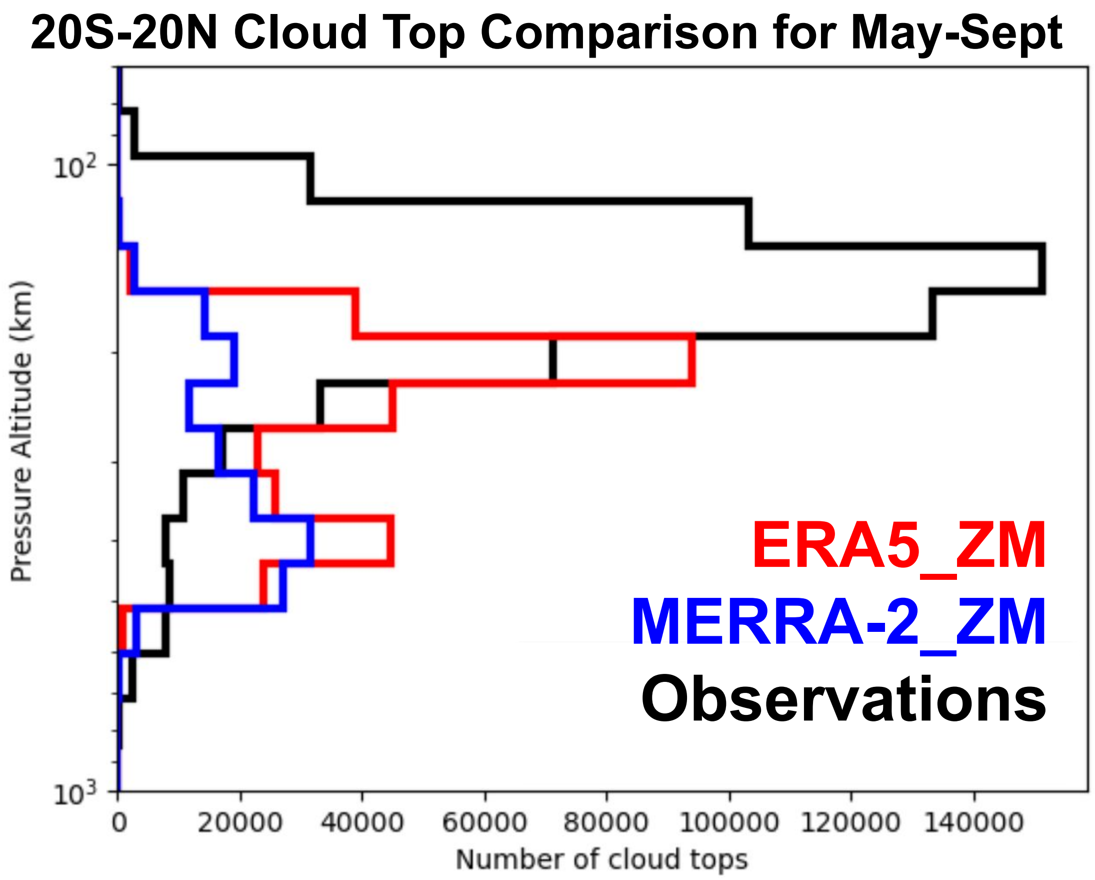


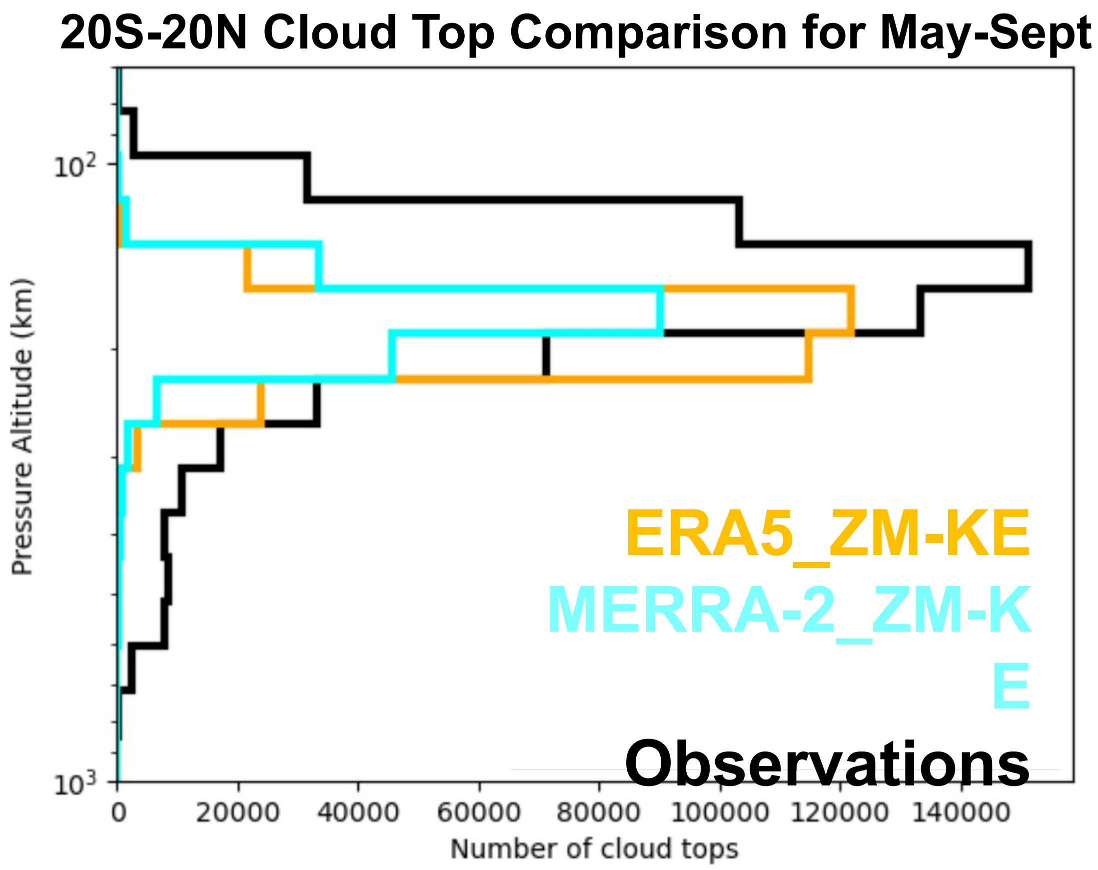
Cloud top observations from CloudSat / TRMM courtesy of Rei Ueyama (NASA)



2022 Carbon Monoxide (CO) difference for ERA5_ZM minus MERRA-2_ZM

ZM-KE improvement deepens convective cloud top, improving representation with obs





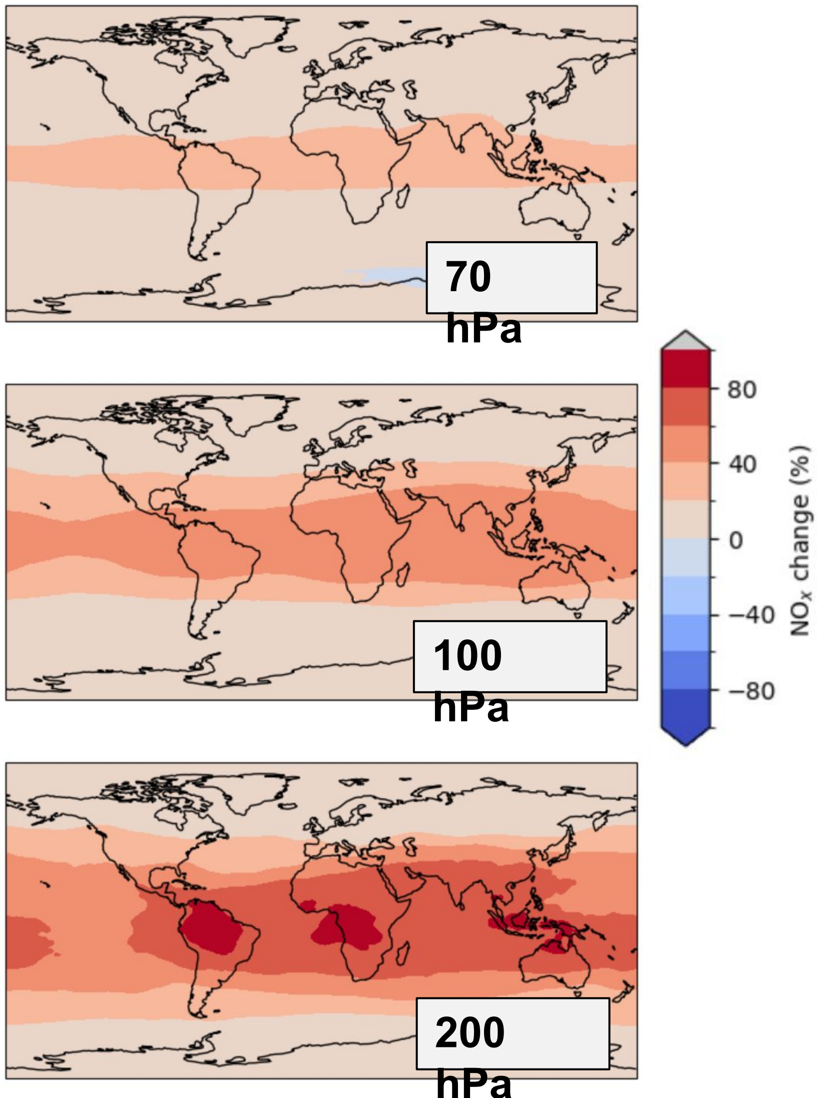
Cloud top observations from CloudSat / TRMM courtesy of Rei Ueyama (NASA)

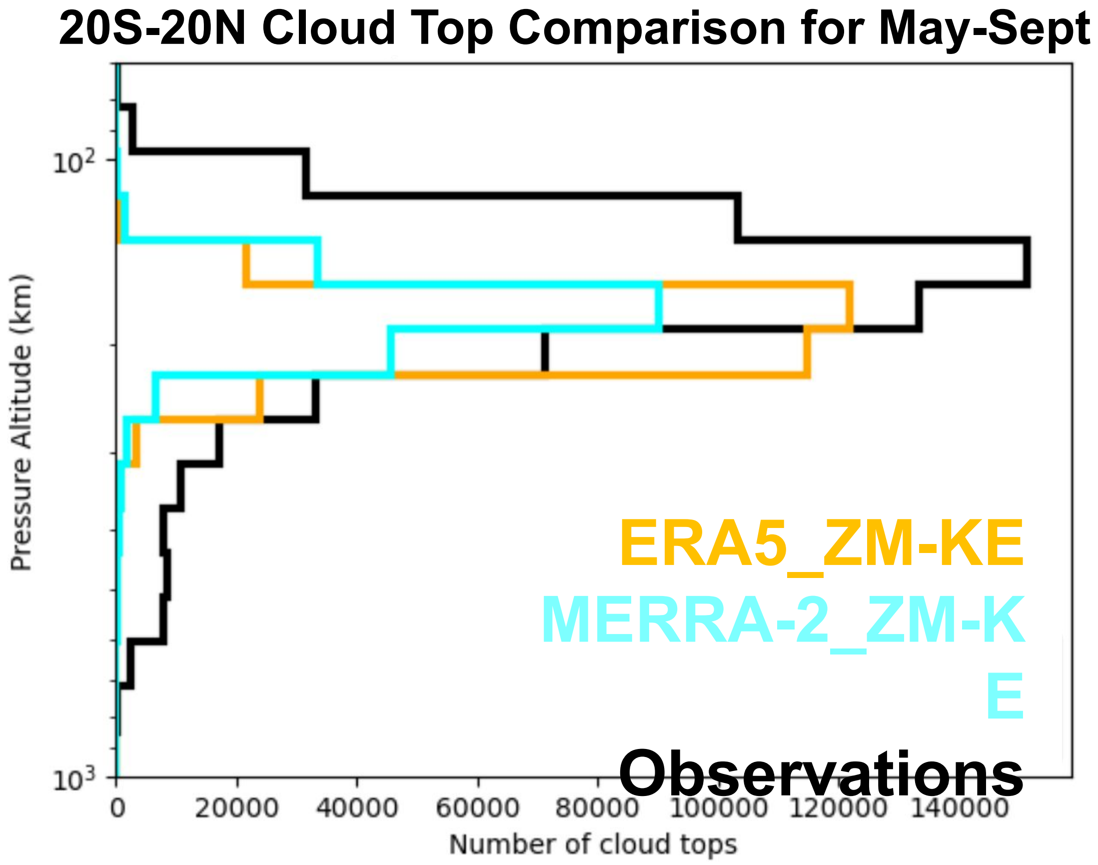
Deepened cloud tops have a massive impact on lightning NOx generation

2022 NOx difference for ERA5_ZM-KE minus ERA5_ZM

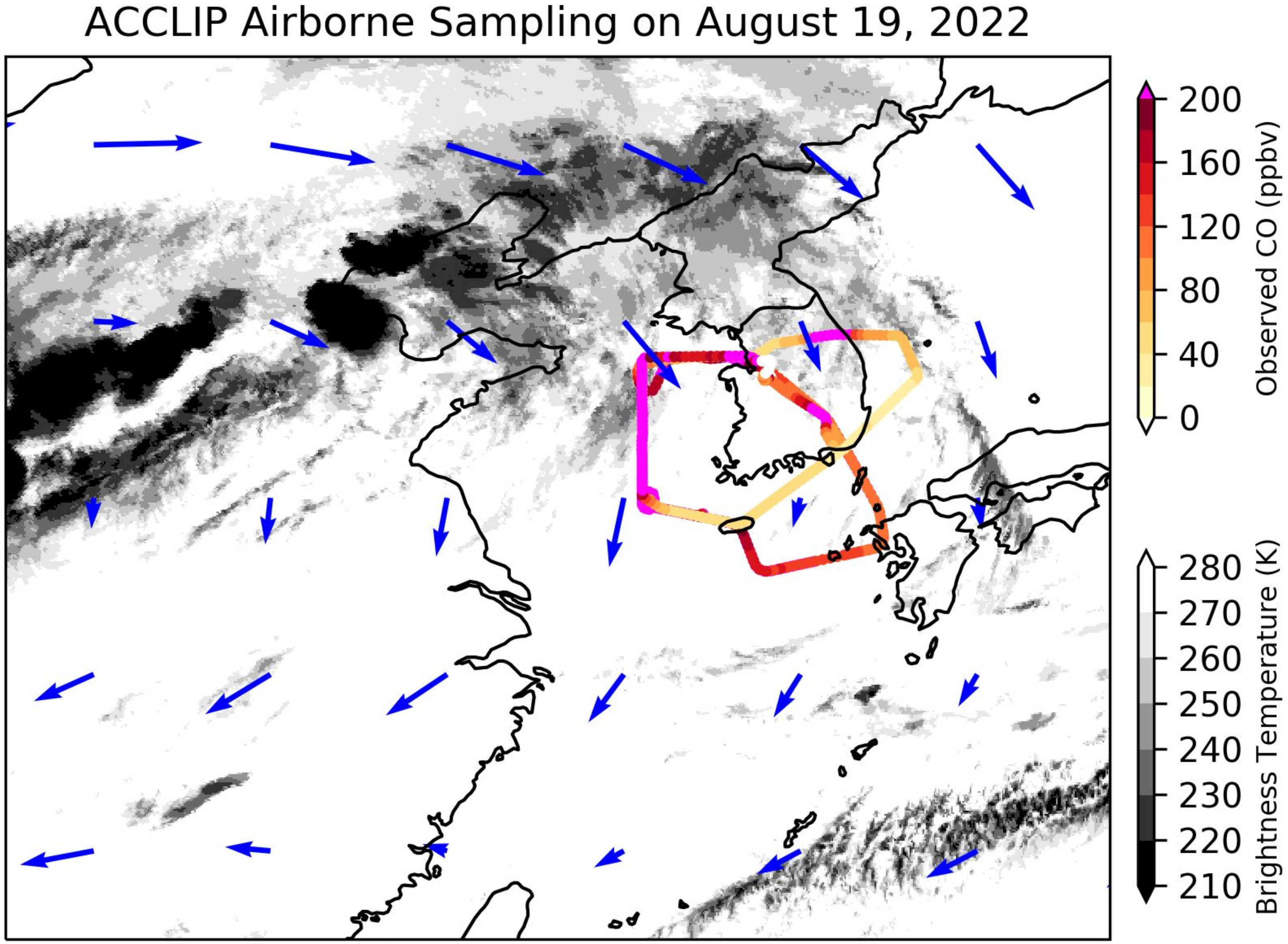
20-40% increase in tropical LS

Up to 80% increase in tropical UT!!

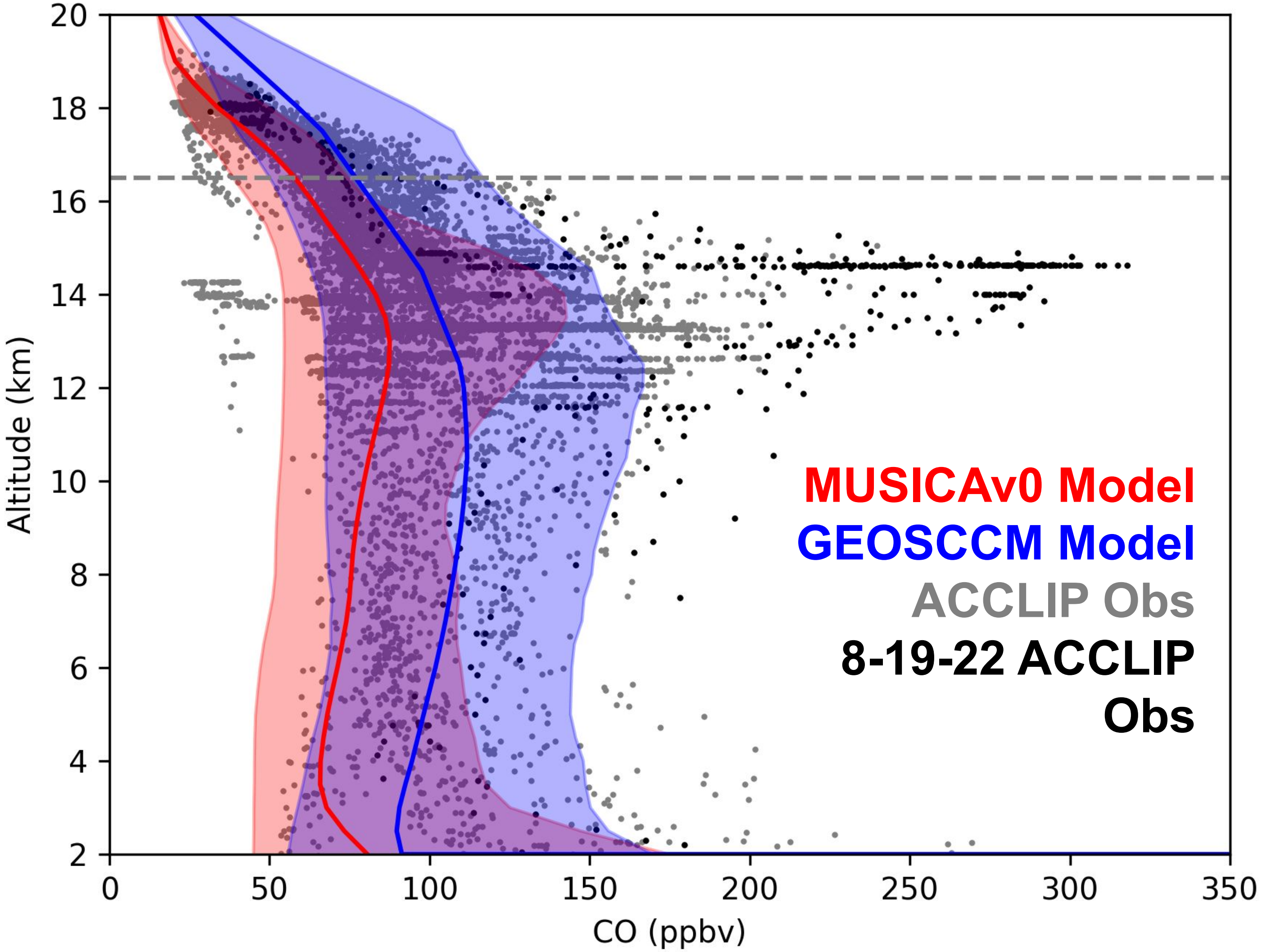




Case Study from ACCLIP (2022): Record-setting ~15 km CO concentration (>300 ppbv)



In-field chemical forecasts struggled with this record-setting pollution event

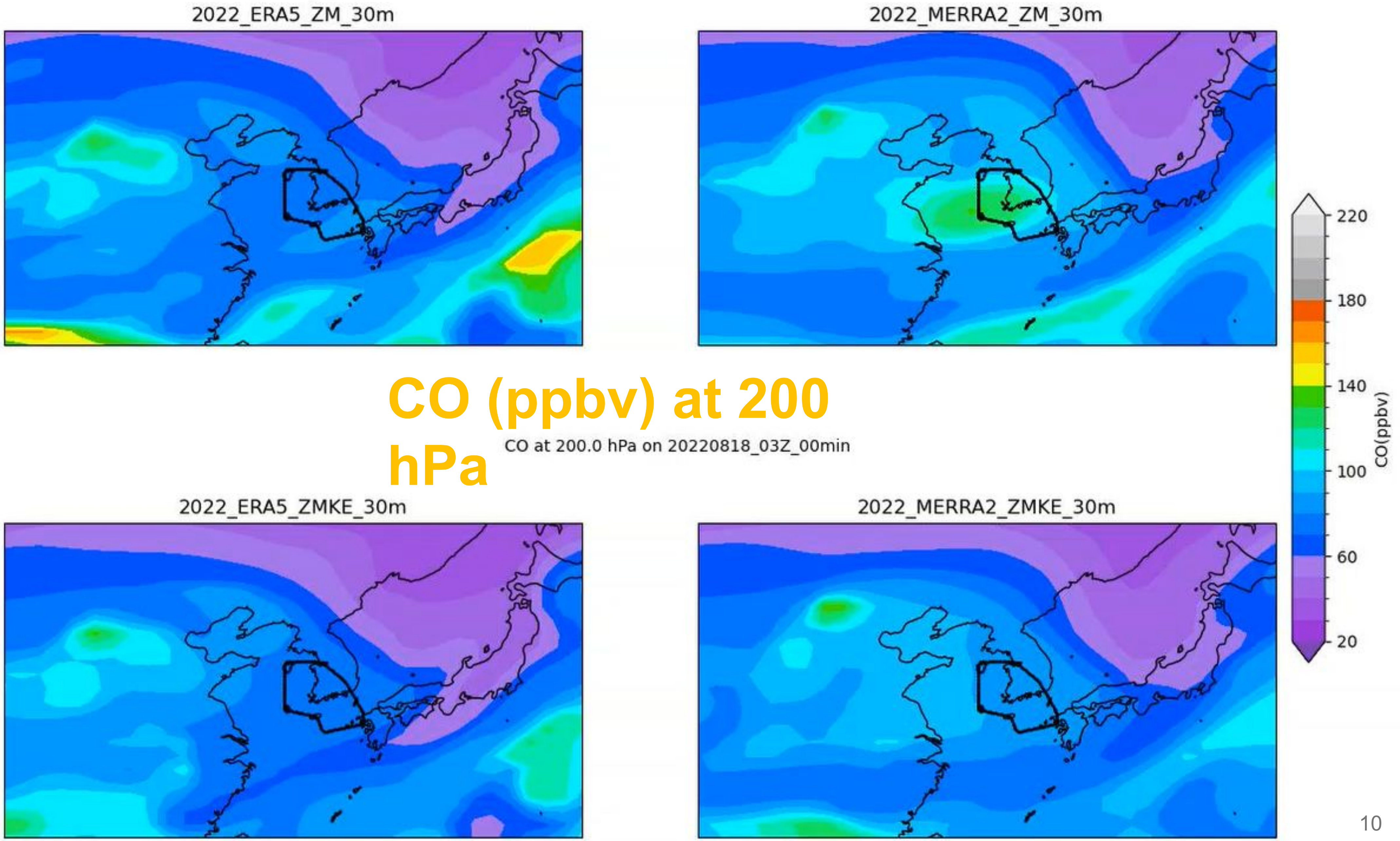


ERA5 MERRA-2

ZM

ZM-KE

CO (ppbv) at 200 hPa



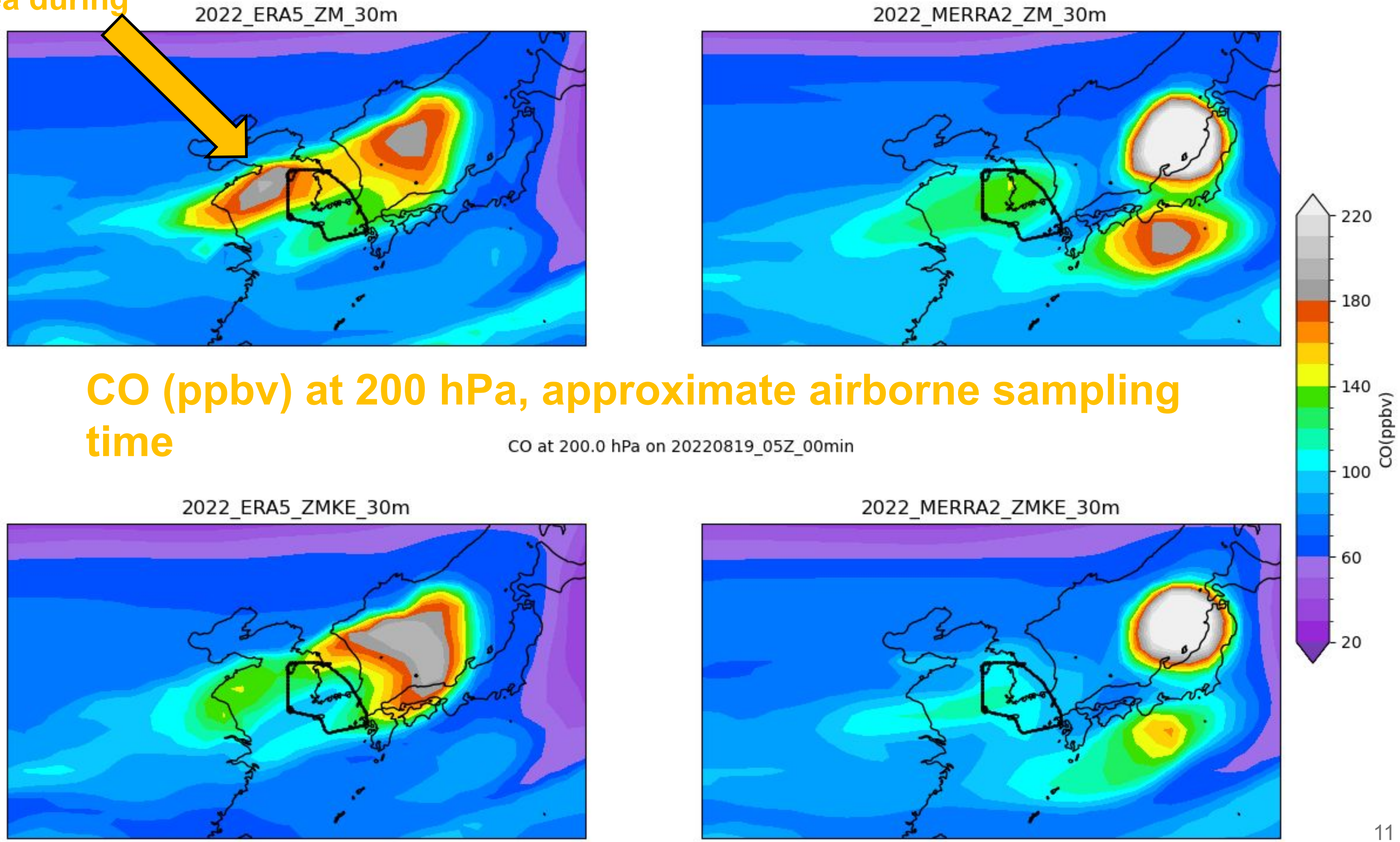
Only simulation with primary CO plume over the Yellow Sea during sampling

ERA5 | MERRA-2

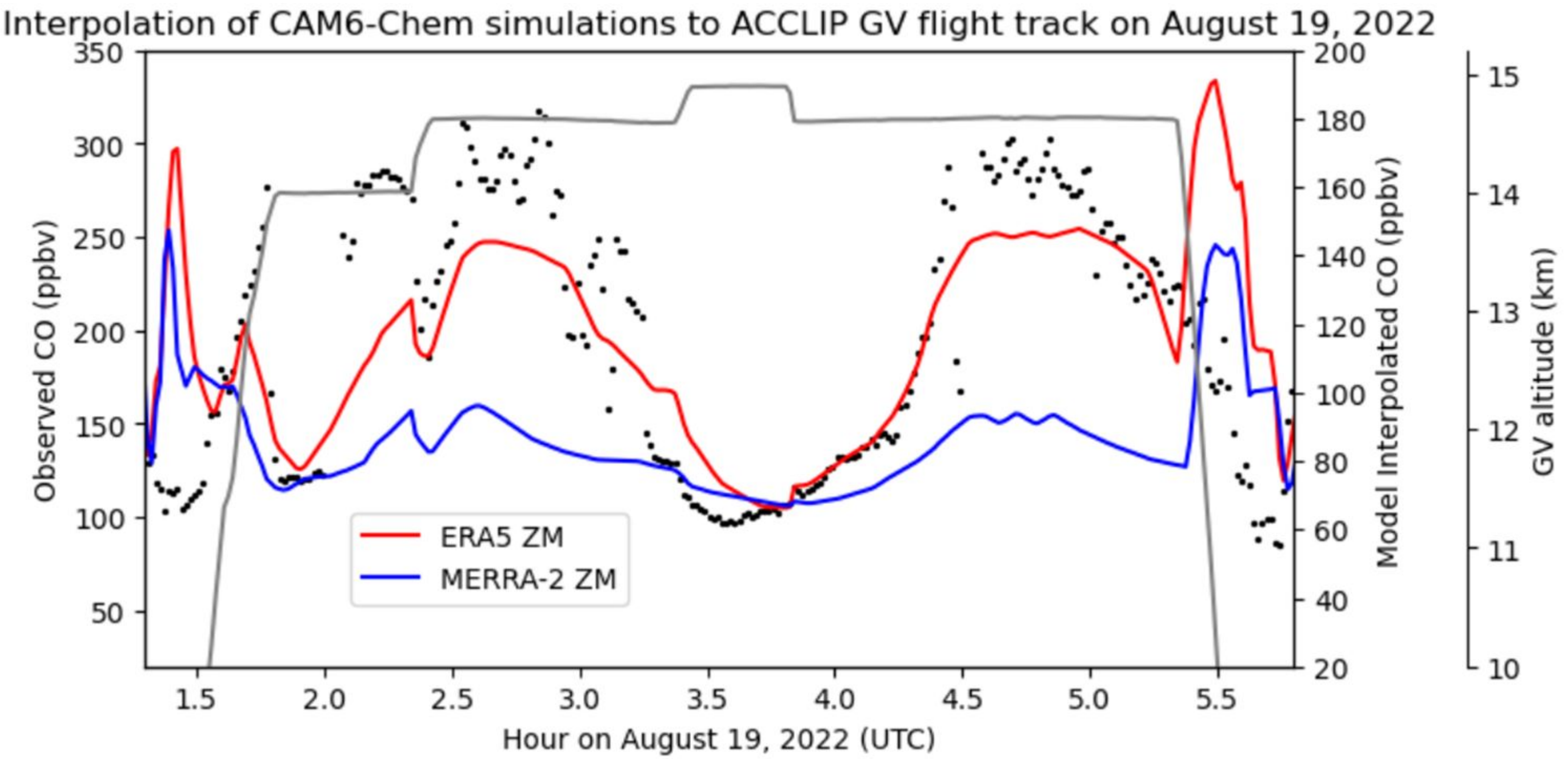
ZM

ZM-KE

CO (ppbv) at 200 hPa, approximate airborne sampling time

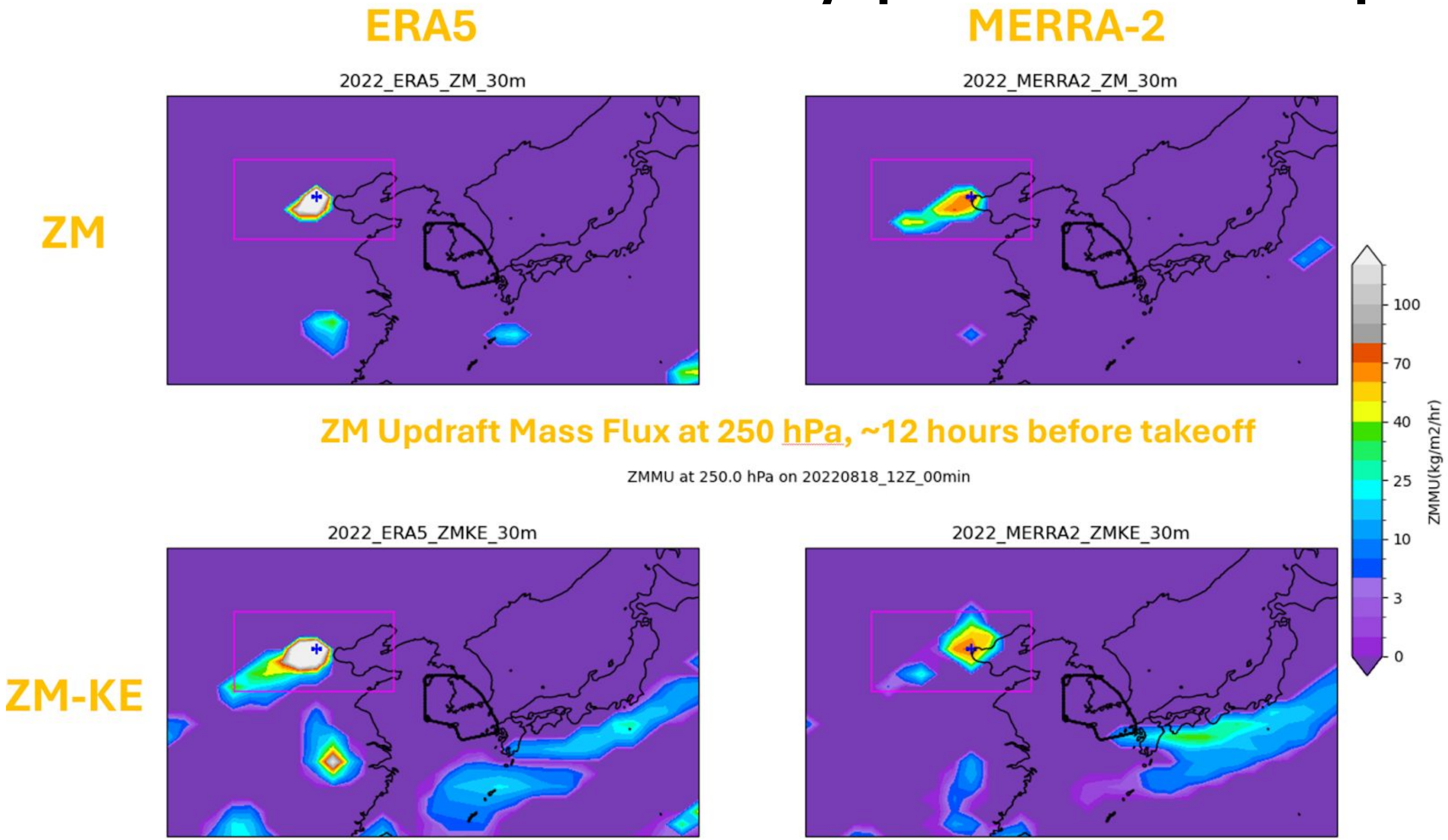


Timing of the CO plume is excellently represented when nudging toward ERA5!



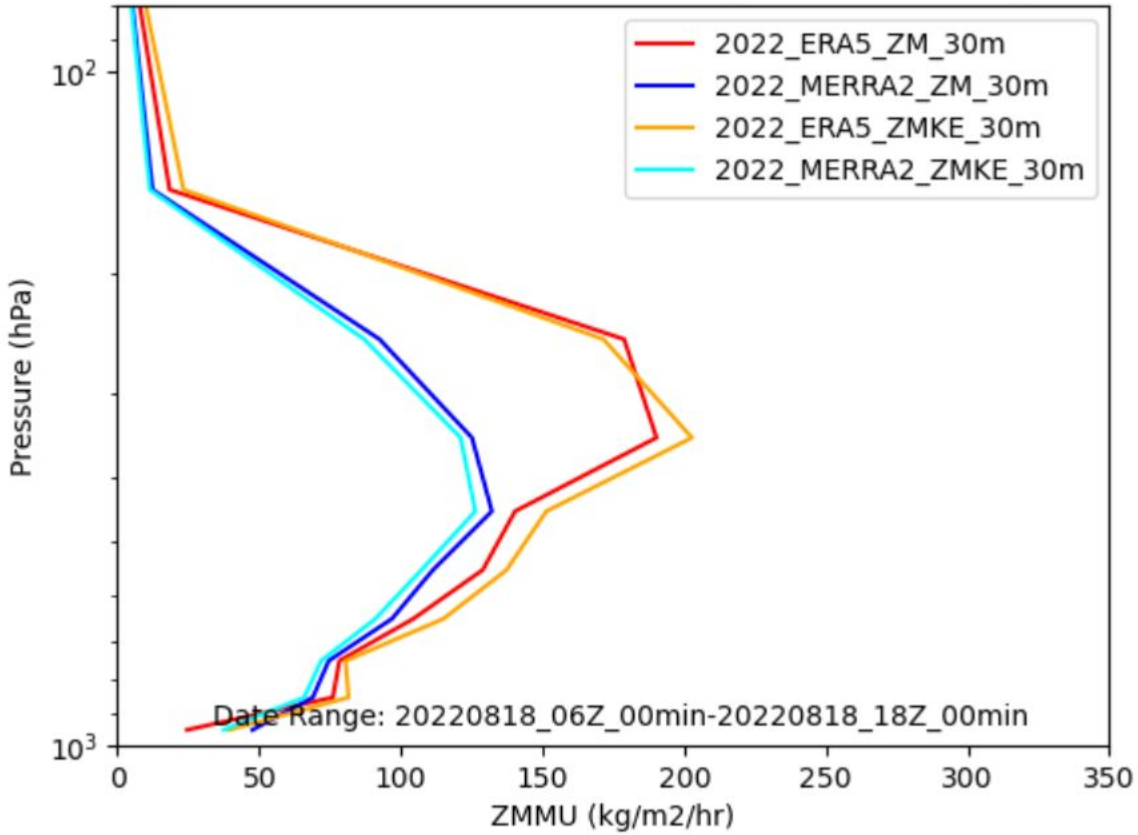
Note different CO axis scales for model/obs
CO observations on the NSF NCAR GV courtesy of T. Campos

All simulations show ZM updraft mass flux over China the day prior to sampling

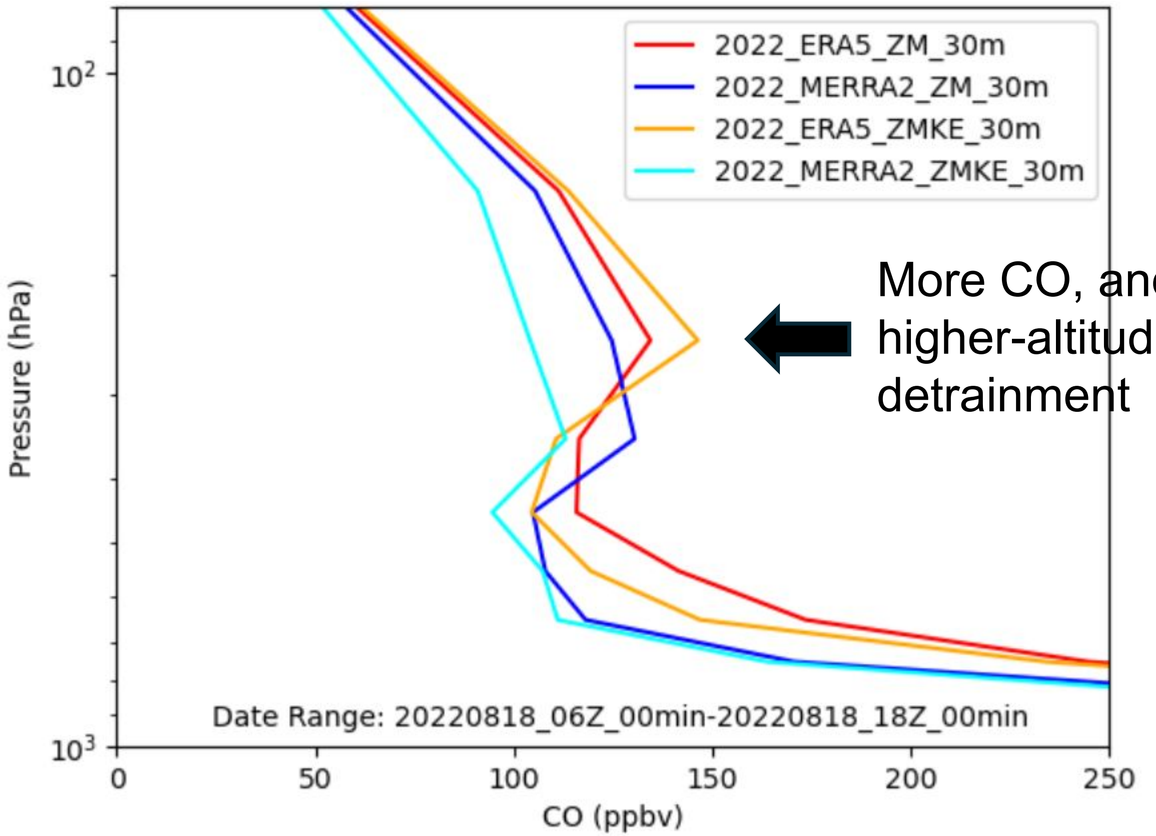


Updraft mass flux is both increased and deepened when nudging toward ERA5

Maximum updraft mass flux profiles in the uplift region, averaged over the uplift period

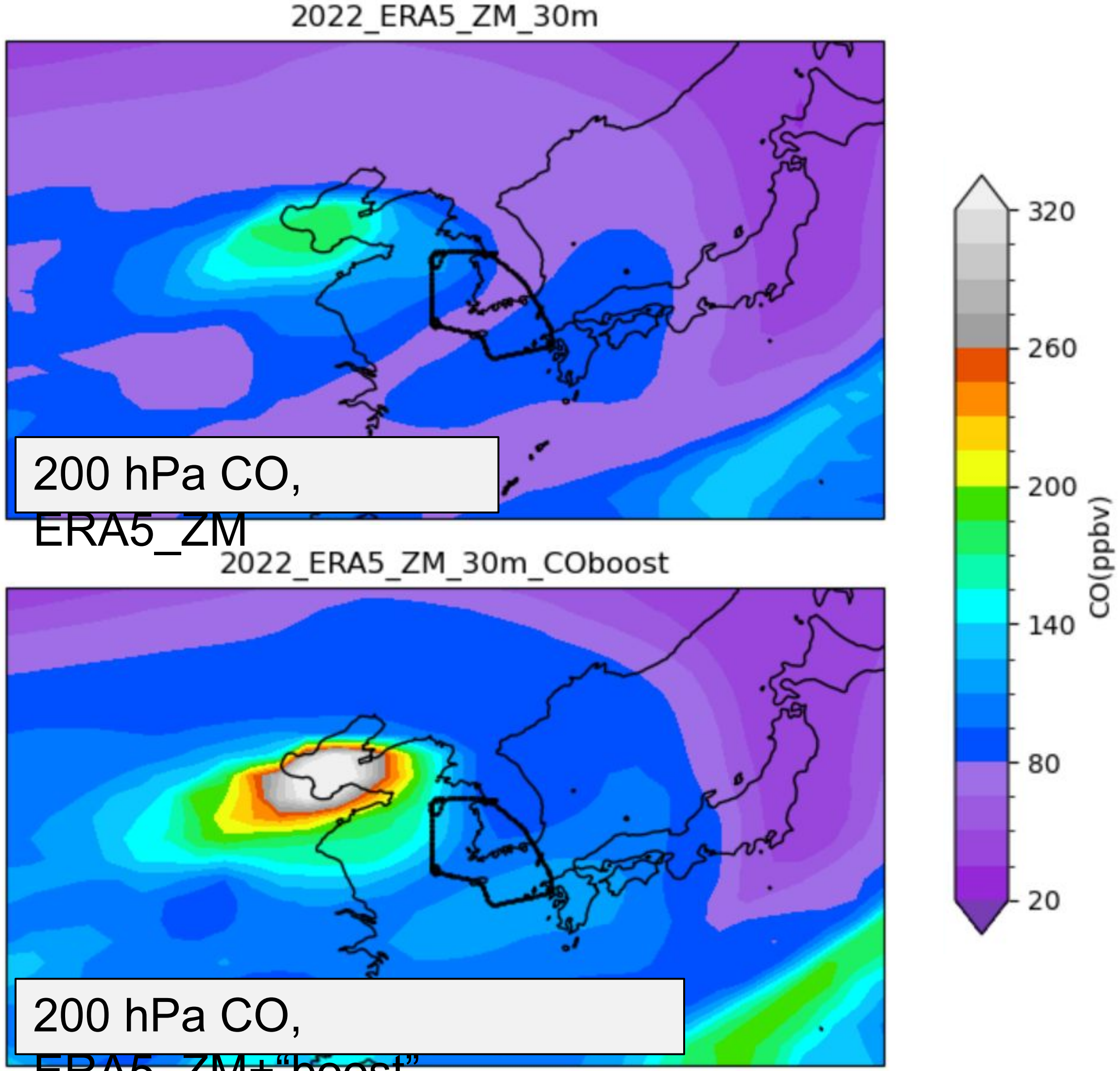


Average CO profiles at the locations of maximum updraft mass flux



More CO, and higher-altitude detrainment

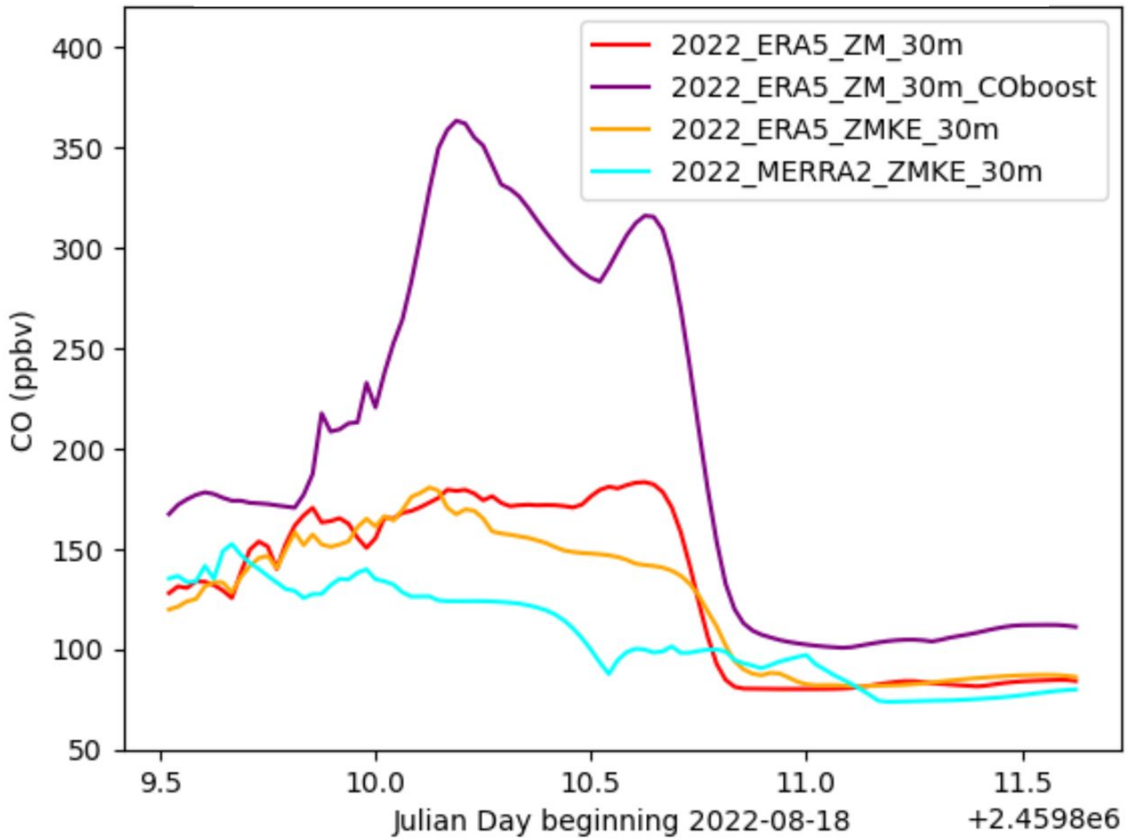
It is *possible* to get CO >300 ppbv in the UT… by doubling emissions and a buoyancy scalar



200 hPa CO, ERA5_ZM

200 hPa CO, ERA5_ZM+"boost"

Time series of maximum 200 hPa CO in convective uplift domain

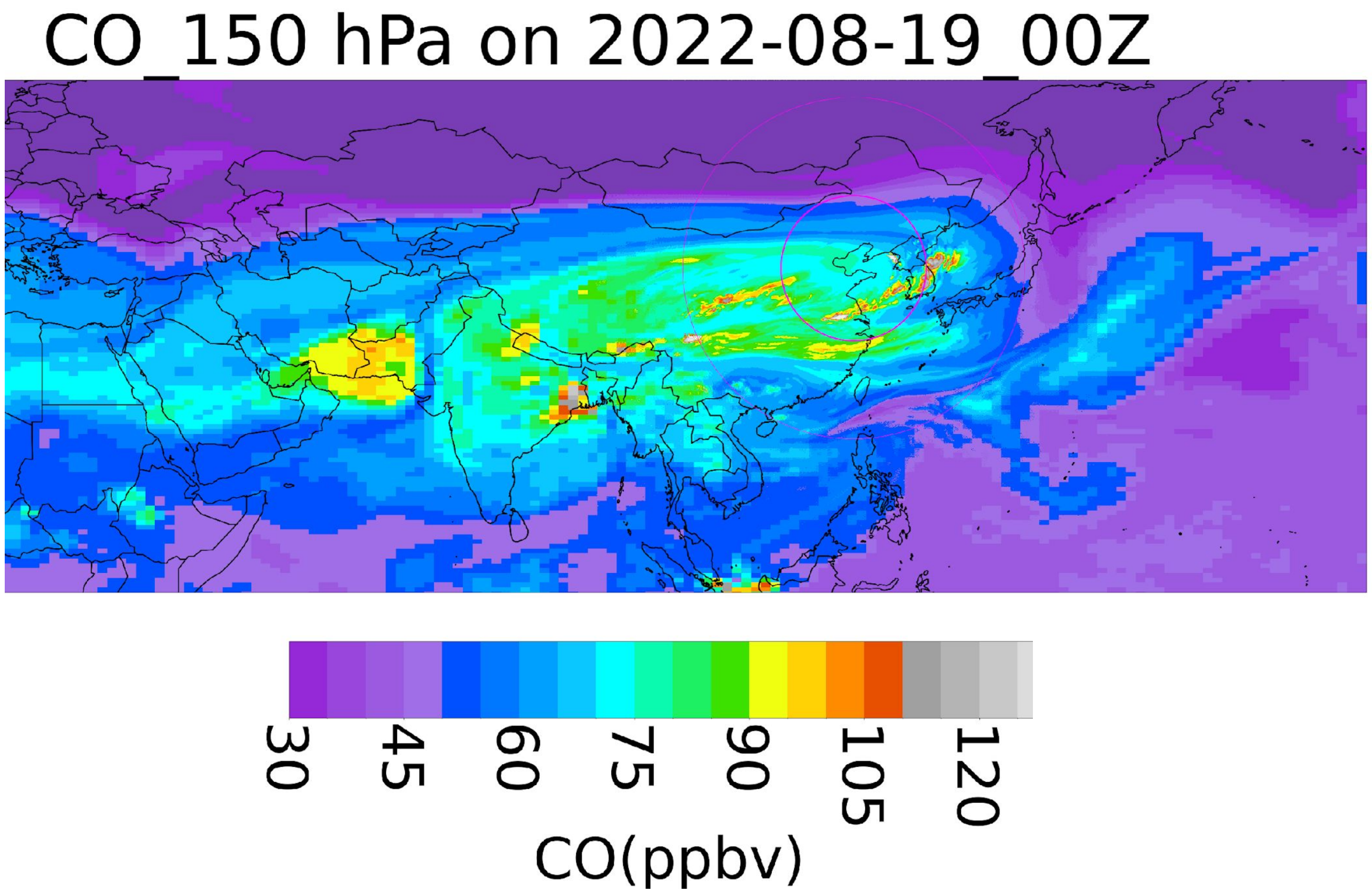


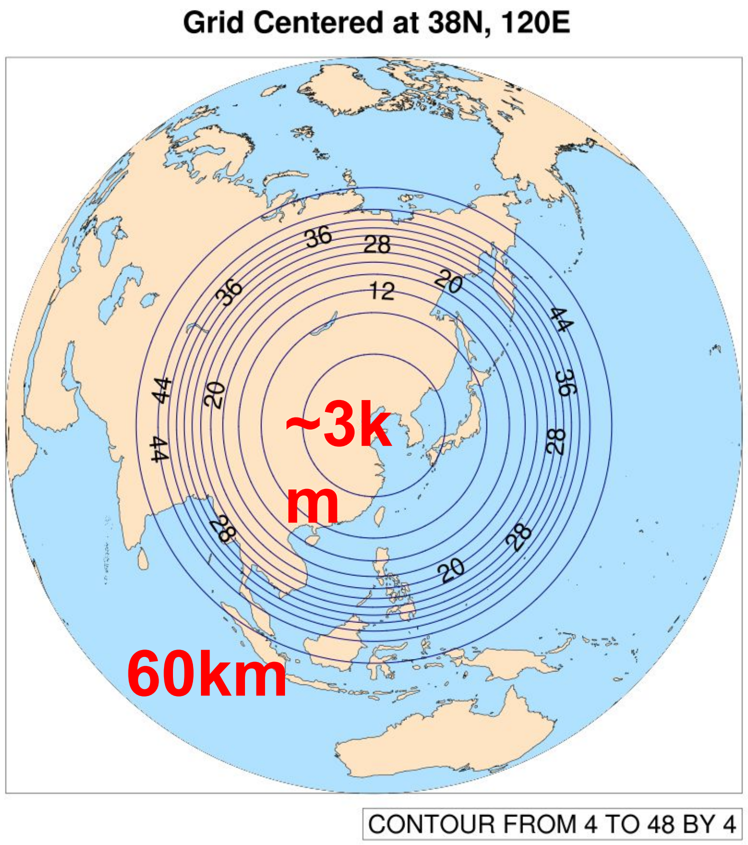
Take-home messages

- Tropical deep convection abundance and depth improve with:
  - Nudging toward ERA5, compared to MERRA-2
  - Using ZM-KE, compared to standard ZM
- Global composition is altered when nudging toward ERA5 and when using ZM-KE, tuning and comparison with obs will be important
- For a prominent pollution transport event, nudging toward ERA5 improves pollution concentration and plume timing in the UT
  - CO transport can be enhanced to match obs, but with questionable realism

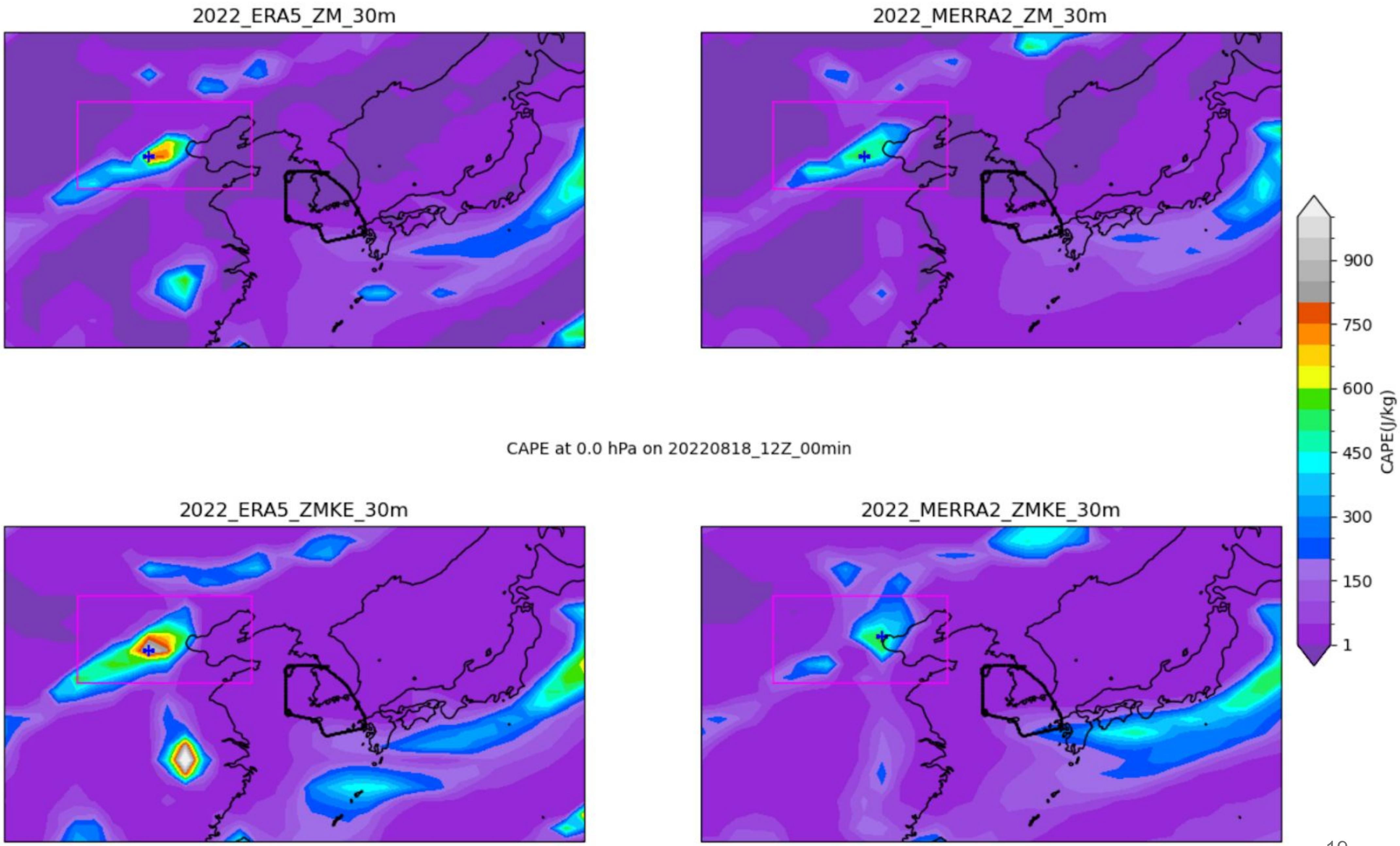
Composition is a unique and important avenue for evaluating the representation of model dynamics!

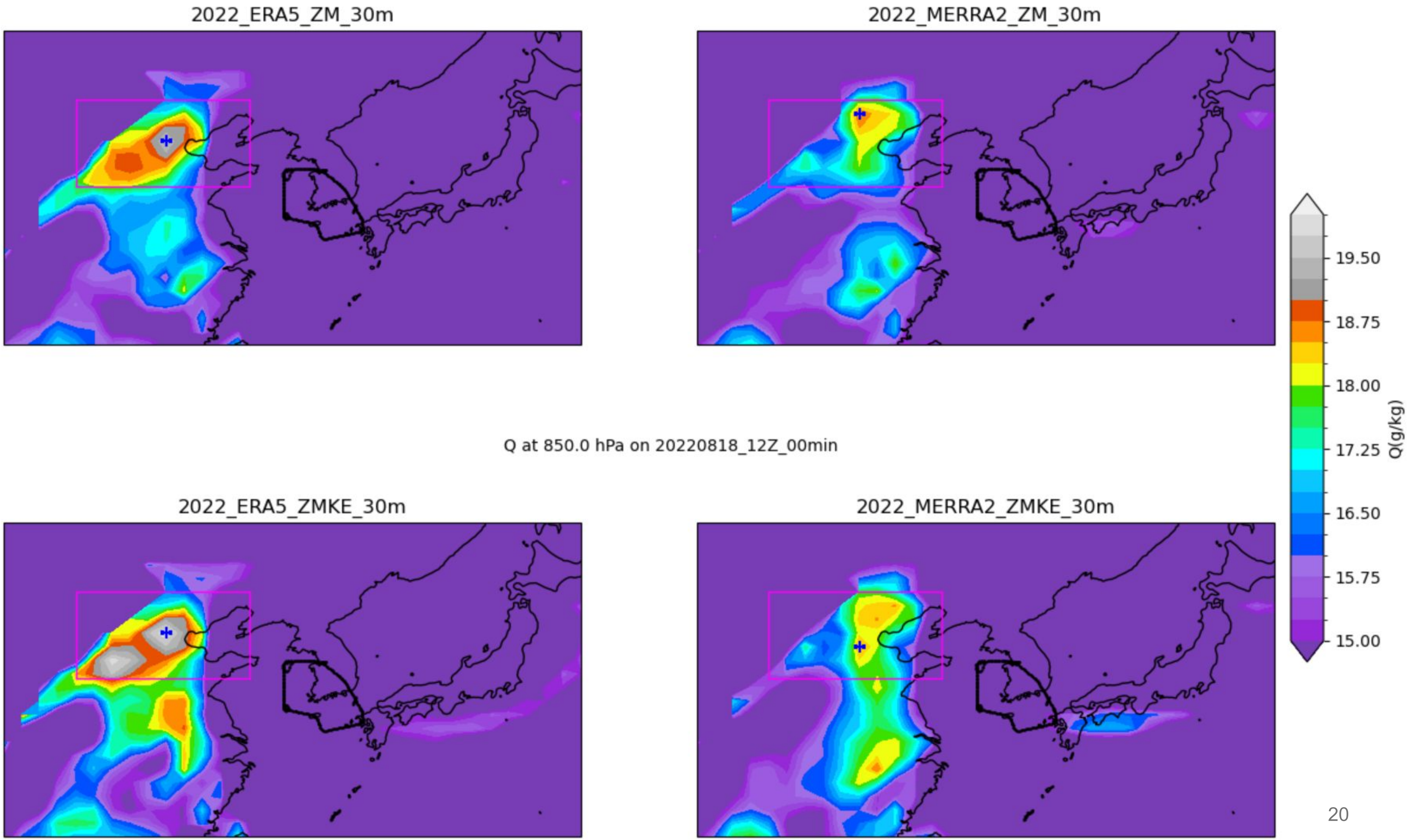
Exploration with MUSICAv1

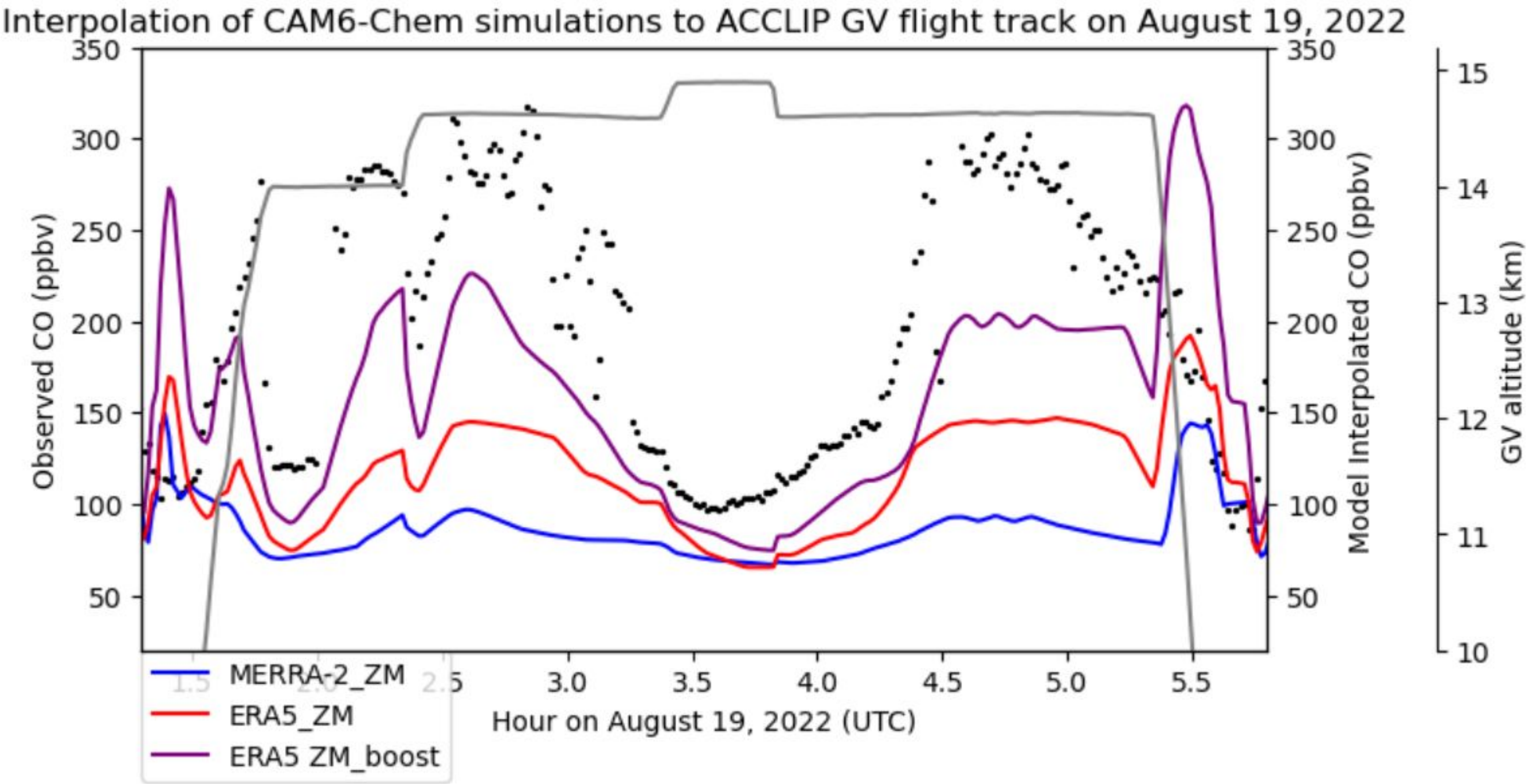




Extra slides


2022_ERA5_ZM_30m
2022_MERRA2_ZM_30m
CAPE at 0.0 hPa on 20220818_12Z_00min
2022_ERA5_ZMKE_30m
2022_MERRA2_ZMKE_30m
900
750
600
450
300
150
1
CAPE(J/kg)


2022_ERA5_ZM_30m
2022_MERRA2_ZM_30m
Q at 850.0 hPa on 20220818_12Z_00min
2022_ERA5_ZMKE_30m
2022_MERRA2_ZMKE_30m
19.50
18.75
18.00
17.25
16.50
15.75
15.00
Q(g/kg)



Interpolation of CAM6-Chem simulations to ACCLIP GV flight track on August 19, 2022
Observed CO (ppbv)
Model Interpolated CO (ppbv)
GV altitude (km)
Hour on August 19, 2022 (UTC)
MERRA-2_ZM
ERA5_ZM
ERA5 ZM_boost
350
300
250
200
150
100
50
15
14
13
12
11
10
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5

Plume Ensemble Formulation (PEF)

Bulk Formulation (BF)

From Lawrence and Rasch (2005)

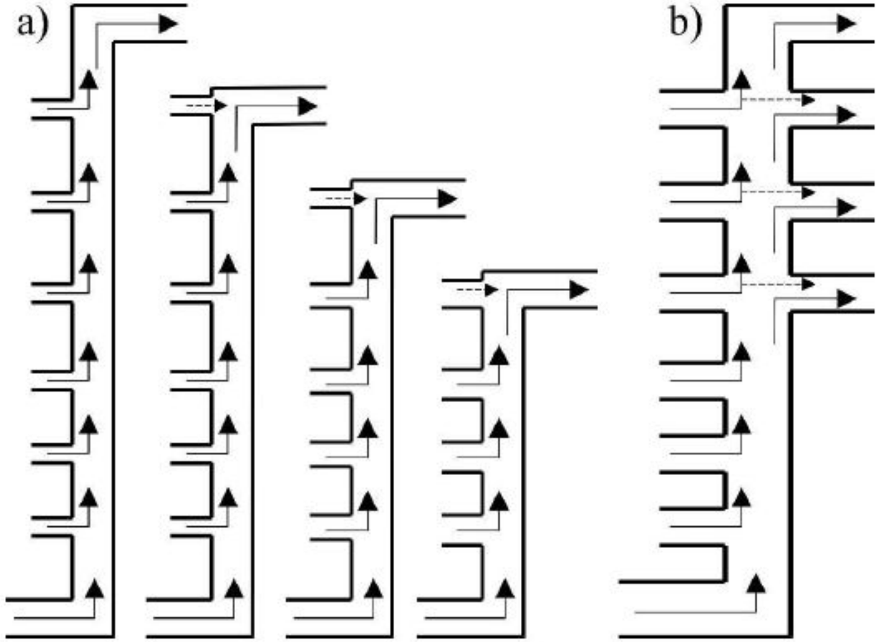


FIG. 1. Schematics of the (a) PEF and (b) BF. Entrainment is represented by arrows entering from the left, detrainment by arrows exiting to the right. There is only a single detrainment layer at the top of the plume for each of the discrete plumes in the PEF. Summing these plumes results in a BF with four detrainment layers in this example.

Bulk Formulation (like ZM) uses a single entrainment rate, so mass flux peaks at single (lower) altitude

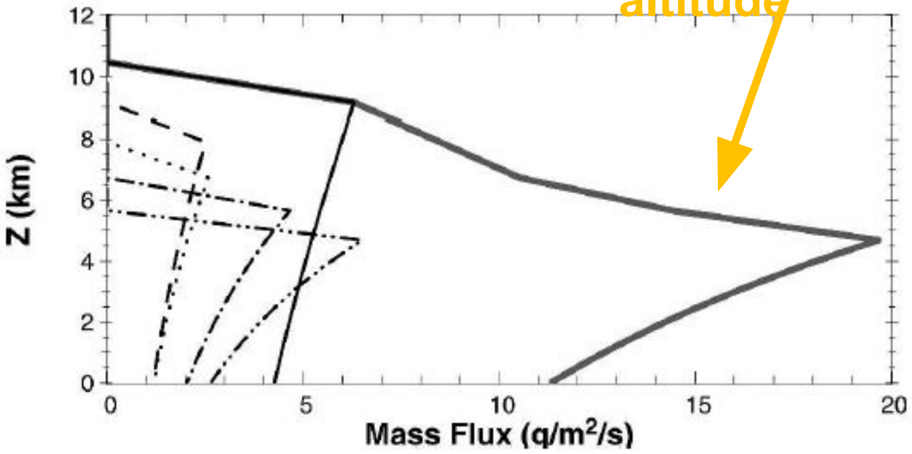


FIG. 2. Sample decomposition of the vertical mass flux profile of a BF plume (thick solid gray line) into its individual discrete PEF members for a model column over central Africa. The thin lines of different types represent each discrete plume, with the thin solid line being the tallest plume and the dash–dot–dot line being the shortest plume.

$$\lambda = \frac{1}{M}\frac{dM}{dz}$$

At the altitude where d(Mass_Flux)/dz changes sign, entrainment will become negative and the plume should thus *detrain* tracers