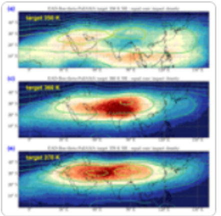
Confinement of Air and its Pathways to the Stratosphere Within the Asian Summer Monsoon

Research article

28 Sep 2020

Confinement of air in the Asian monsoon anticyclone and pathways of convective air to the stratosphere during the summer season



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Discussion of Legras and Bucci (2020)

Presented by Ren Smith (NCAR/ACOM)

UTLS Group Meeting

February 23, 2021

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https://acp.copernicus.org/articles/20/11045/2020/

Outline of Legras and Bucci (2020)

- Recaps prior findings of transport mechanisms for BL air to enter the monsoon stratosphere
- Runs forward and backward trajectories from and to observed convective clouds
  - Examines distributions of impact and source regions
  - Examines age of parcels as they vertically disperse
- Develops a 1-D model to characterize monsoon confinement for comparison with trajectory findings
- Summarizes results in context of prior findings / mechanisms

Findings I will cover from Legras and Bucci

Question 1: How does convectively lofted air enter the stratosphere?

- Air masses lofted by convection spread horizontally and undergo slow radiative ascent, in accordance with the “blower” mechanism

Question 2: What are the source regions of air entering the stratosphere?

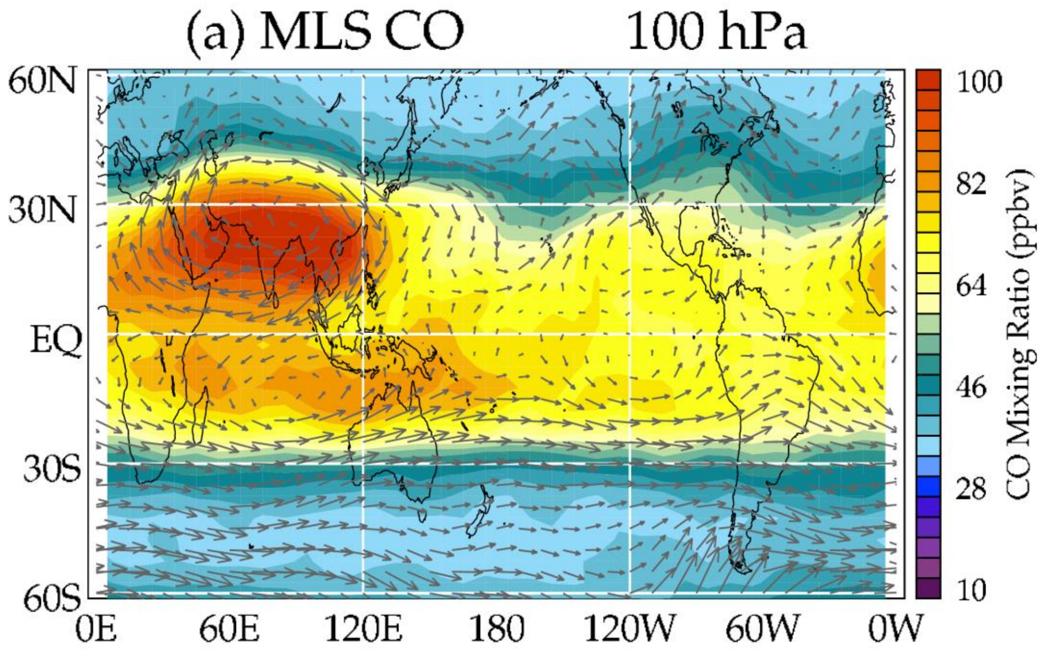
- Transport of convective air masses that cross the monsoon tropopause are primarily of continental origin, especially favoring Plateau origin

Question 3: How do different reanalyses represent these processes?

- ERA-I and ERA5 are qualitatively similar and correlate well, but are quantitatively different

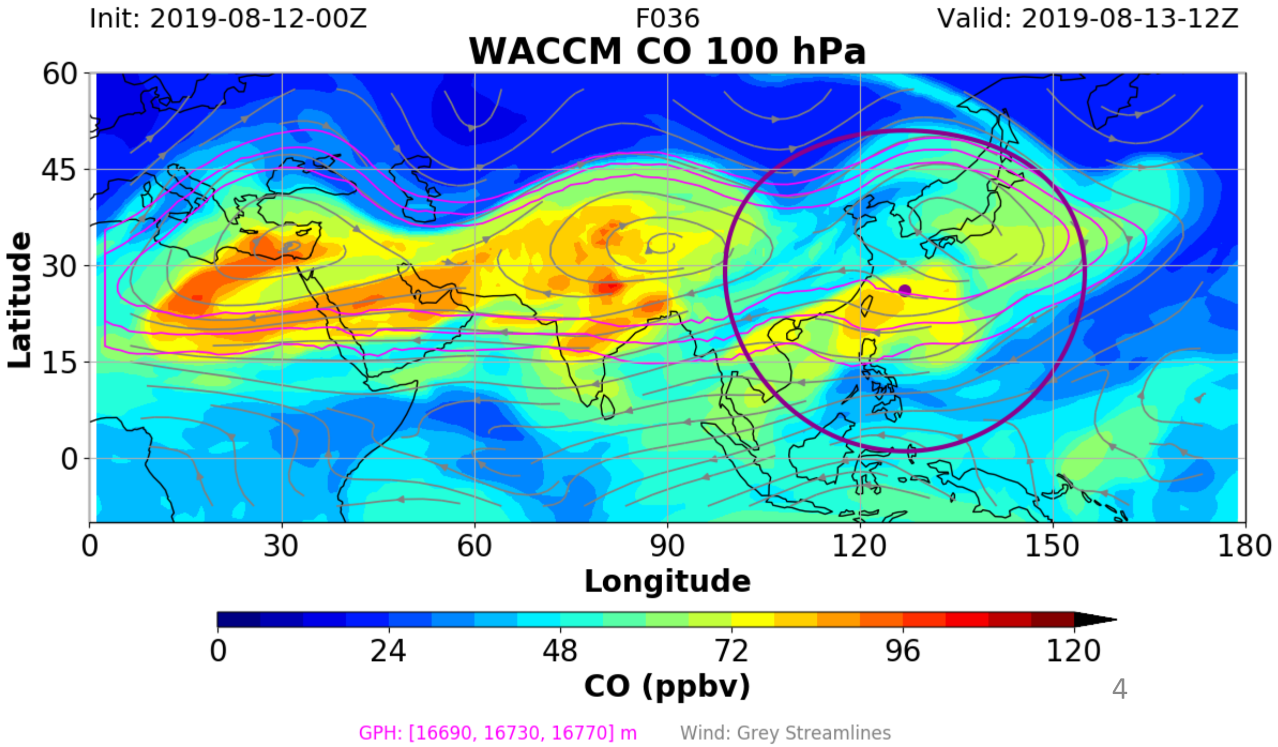
The Asian Monsoon Anticyclone (AMA) is associated with a UTLS enhancement of tropospheric compounds

Satellite Observations
Seasonal Structure

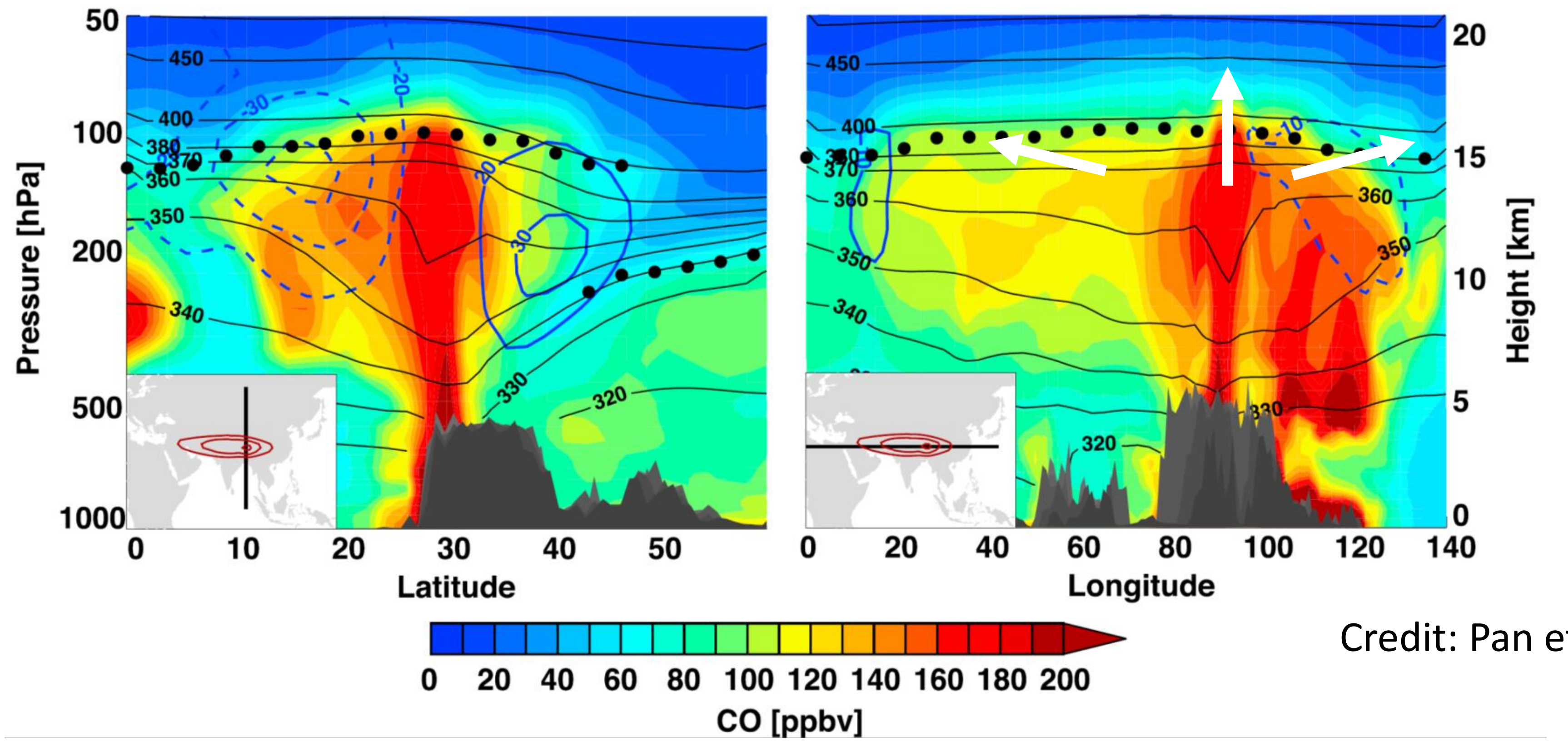


Credit: Park et al (2009)

Numerical Models
Daily Variability



Question 1: How does convectively lofted air enter the stratosphere?

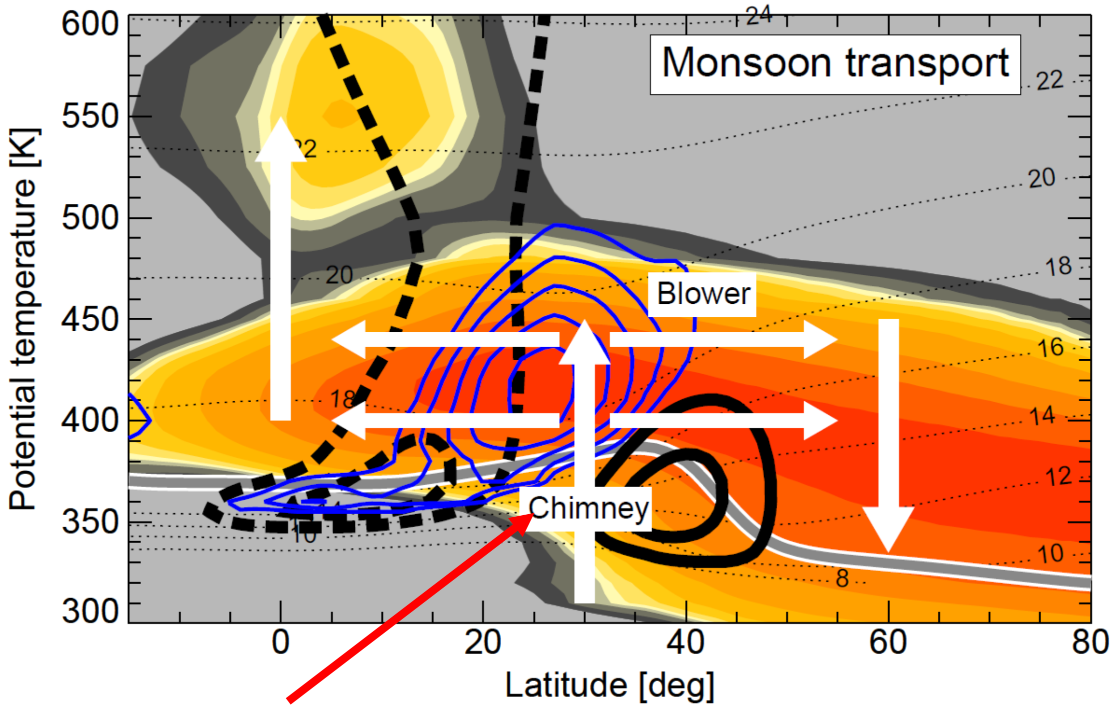


Credit: Pan et al (2016)

Does convectively detrained air continue vertical ascent ("chimney"), or does it spread horizontally as it ascends ("blower")?

Question 1: How does convectively lofted air enter the stratosphere?

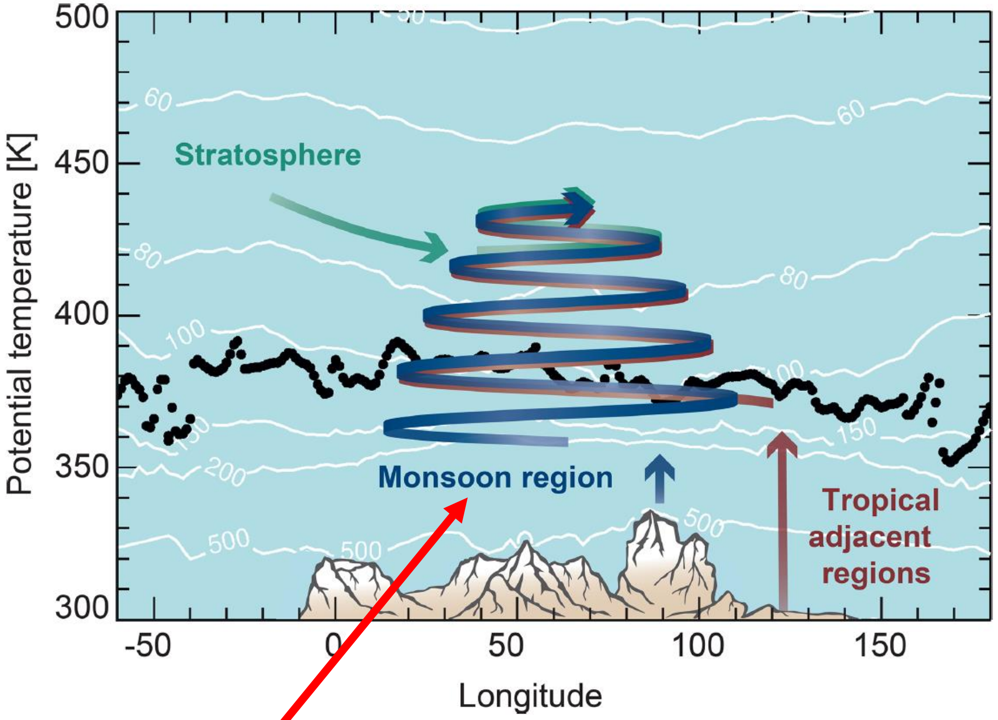
“Chimney”



Credit: Ploeger et al (2017)

Air crossing tropopause as a vertical column

“Blower”



Credit: Vogel et al (2019)

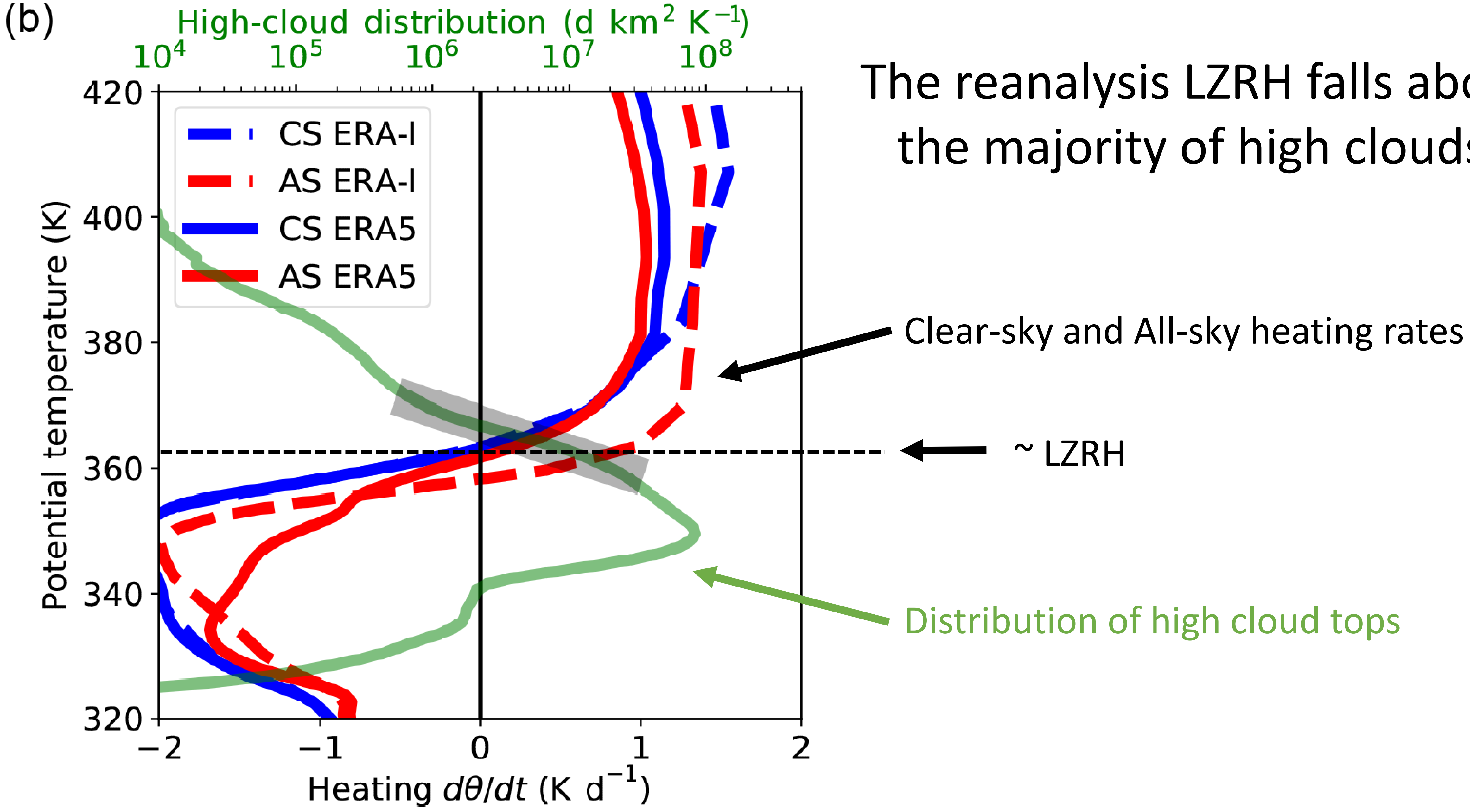
Slow spiraling ascent above convection

Legras and Bucci (2020) approach this debate using a series of trajectories

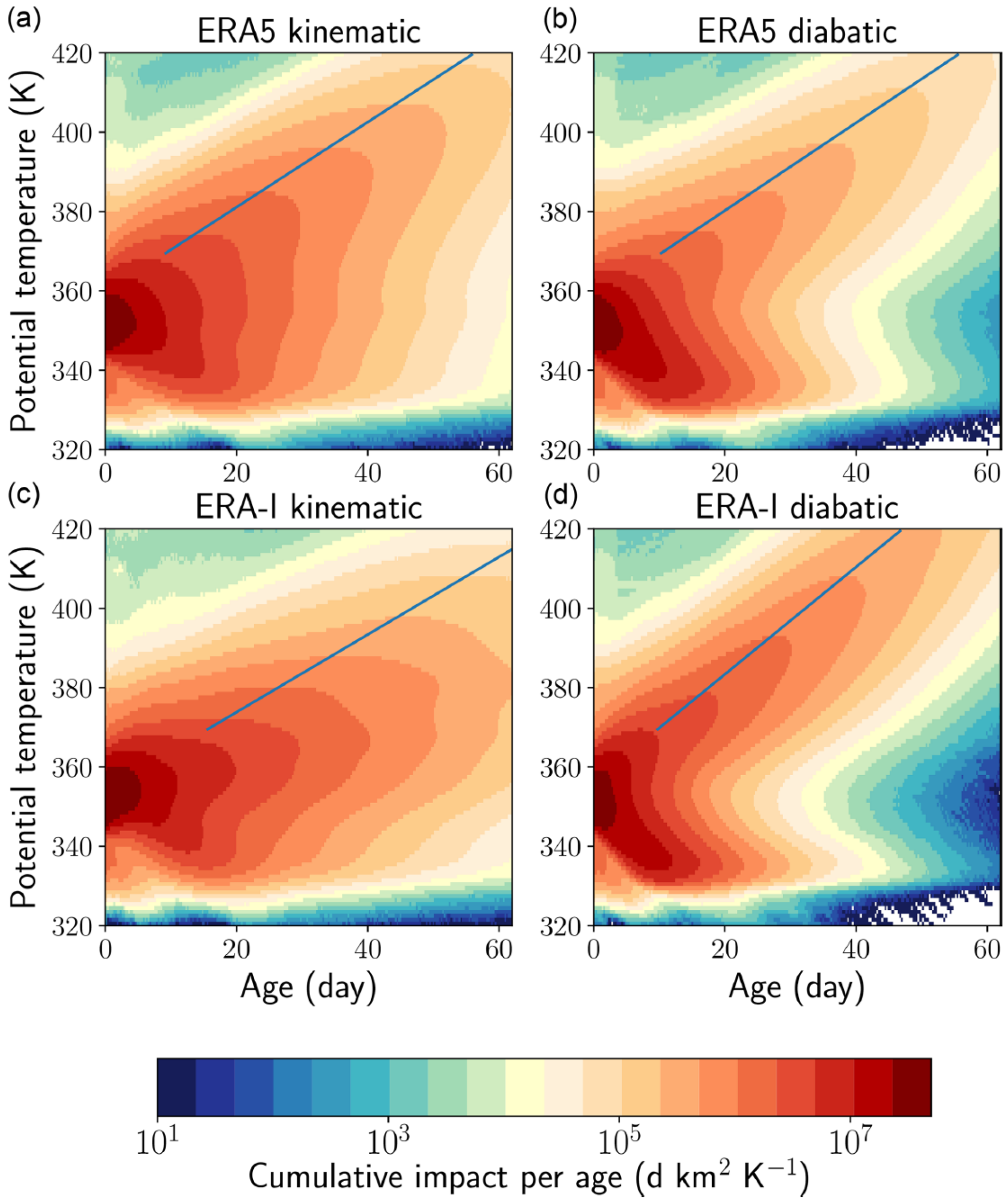
- A suite of 60-day forward trajectories are run from the locations of satellite-observed cloud tops
  - Launches limited to above 250 hPa, within the ASM region, and JJA 2017

- Also runs backward trajectories from selected theta surfaces at 1° resolution every 15 minutes until they reach observed cloud tops

- ERA-I and ERA5 are configured for use in diabatic and kinematic format (emphasis on ERA5 diabatic runs)



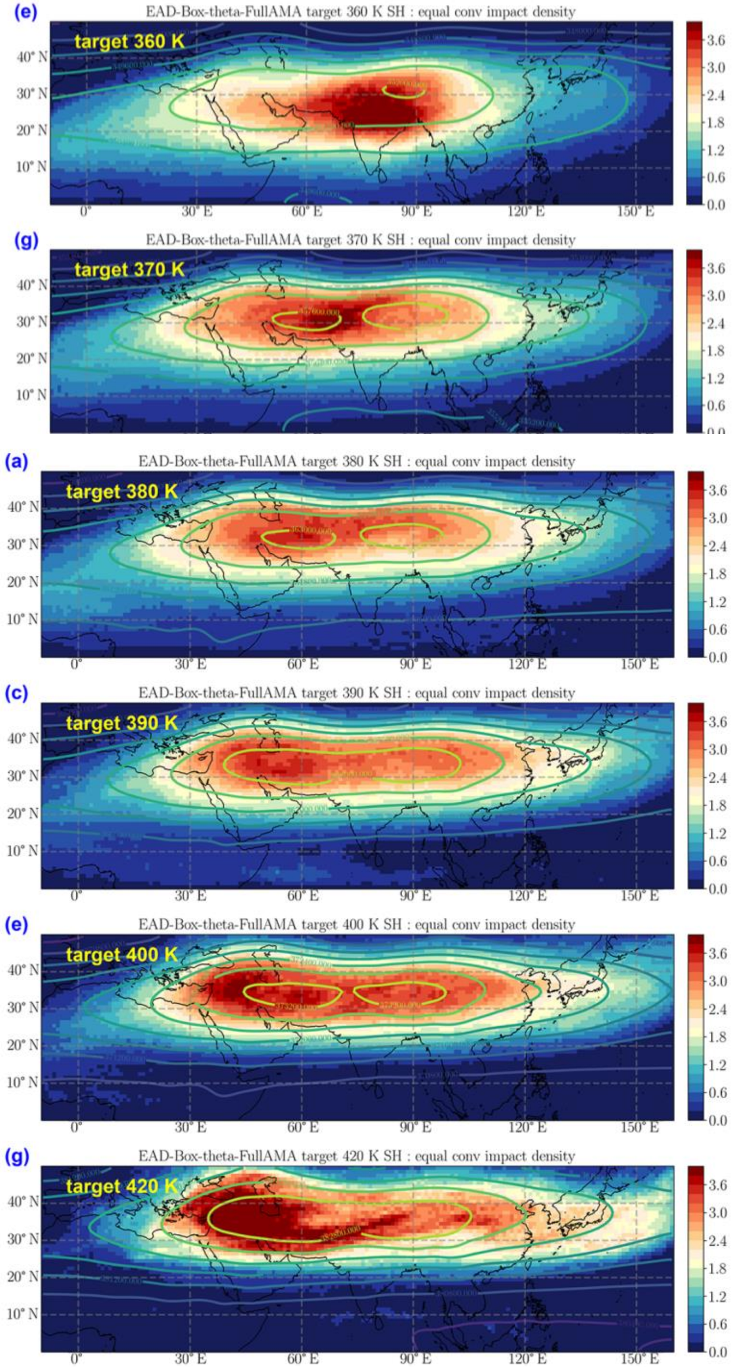
The reanalysis LZRH falls above the majority of high clouds!

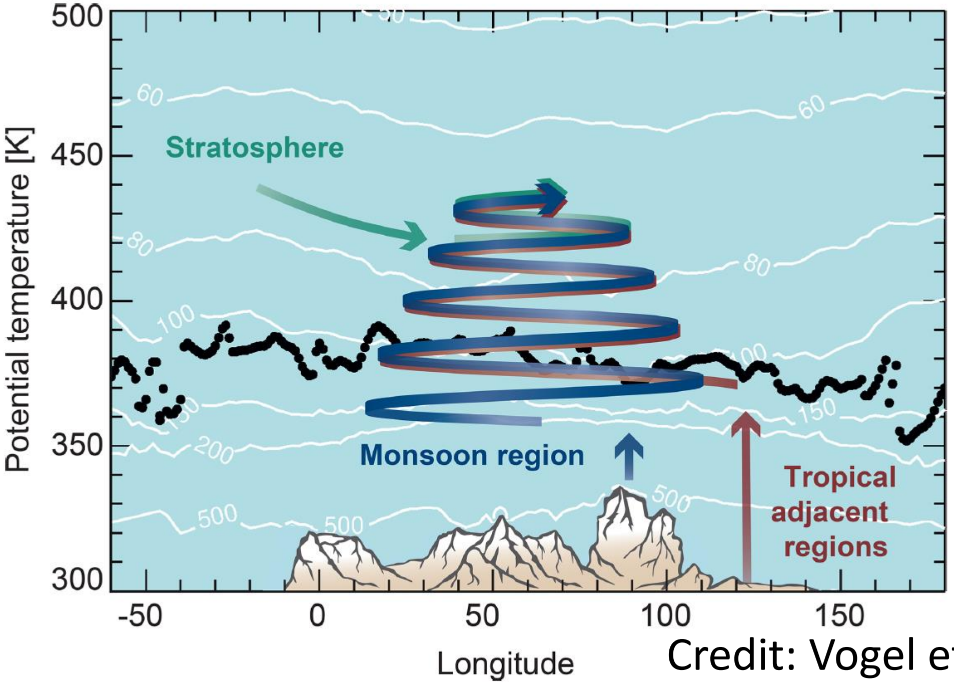


Trajectories ascend and descend from their high-cloud sources, with descent being more intense

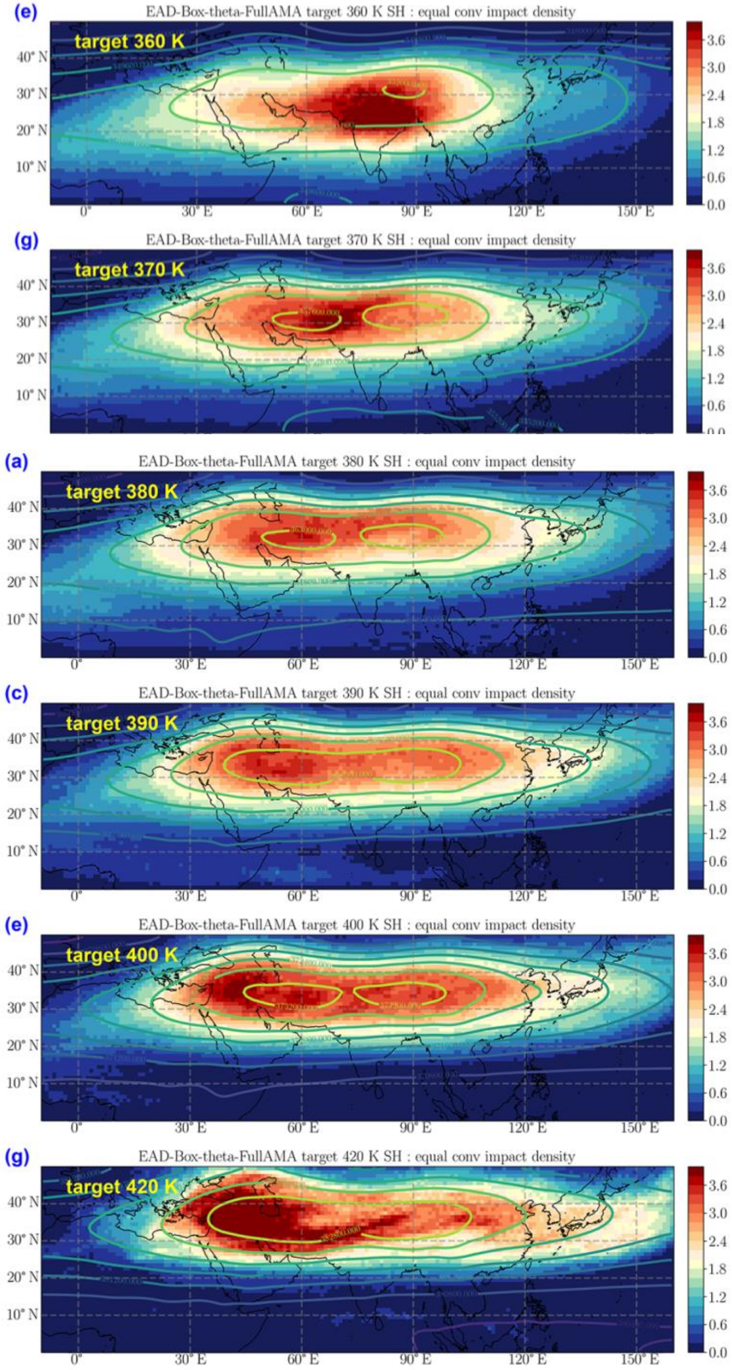
Diabatic trajectories (right) show a sharp separation between ascending and descending branches, brought about by the presence of an LZRH

Air masses retain a columnar structure as they rise, indicating a spiraling ascent (Vogel et al 2019)





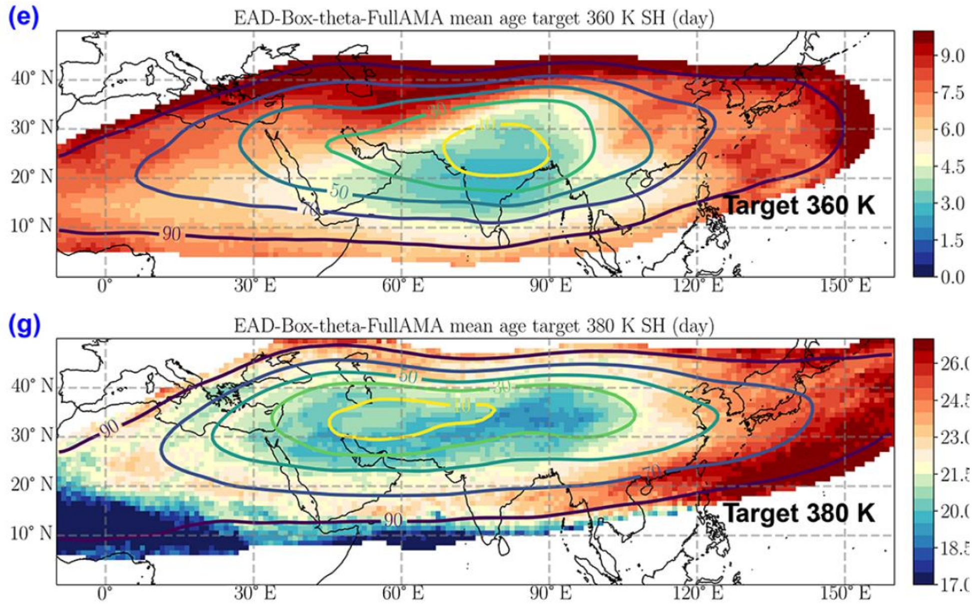
Credit: Vogel et al (2019)



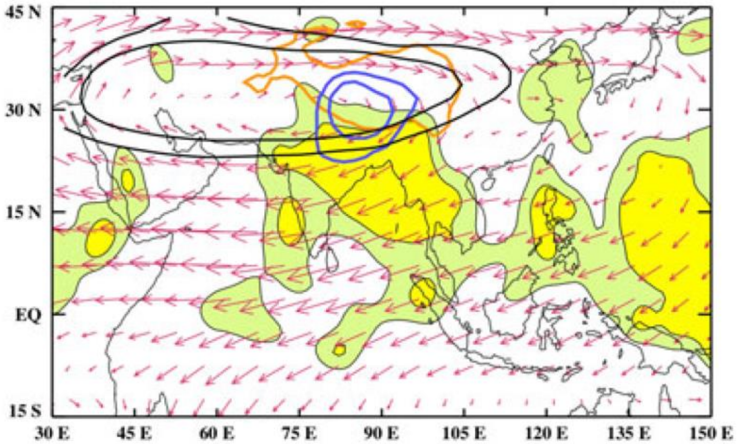
Air masses retain a columnar structure as they rise, indicating a spiraling ascent (Vogel et al 2019)

Distribution of air mass age reveals constant renewal at 360K from beneath convection

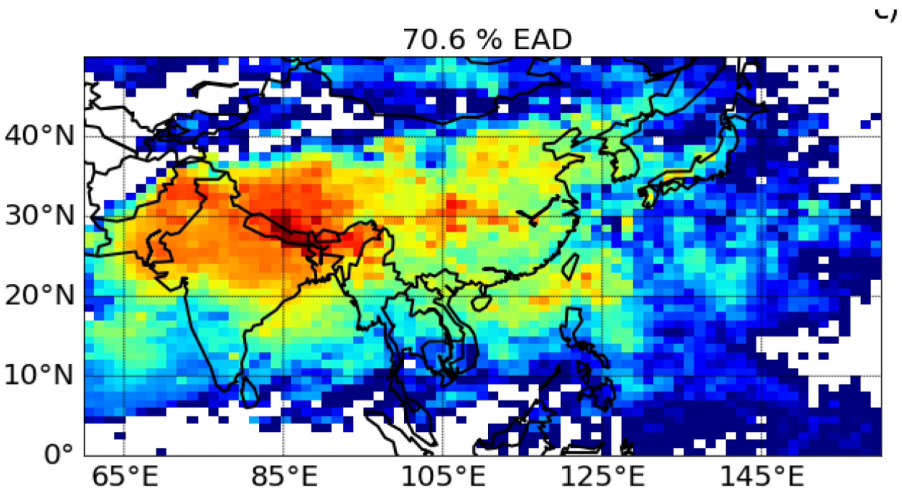
**These support the “blower” hypothesis (Pan et al 2016)



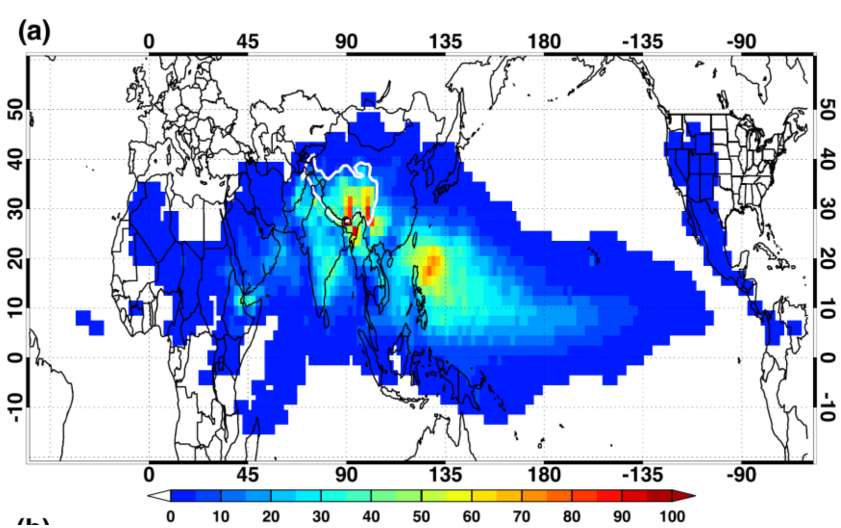
Question 2: What are the source regions for air parcels which reach the stratosphere?



Bergman et al (2013)
Location of a mid-tropospheric "conduit" for preferential uplift

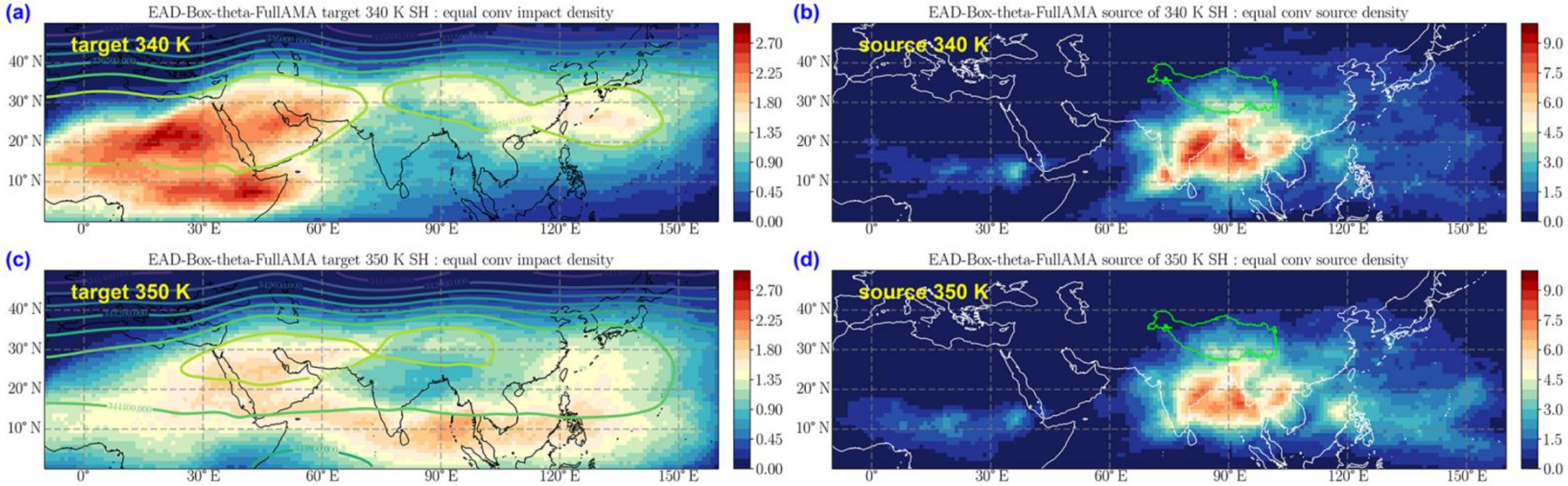


Bucci et al (2020)
Backward trajectories initiated from StratoClim measurements

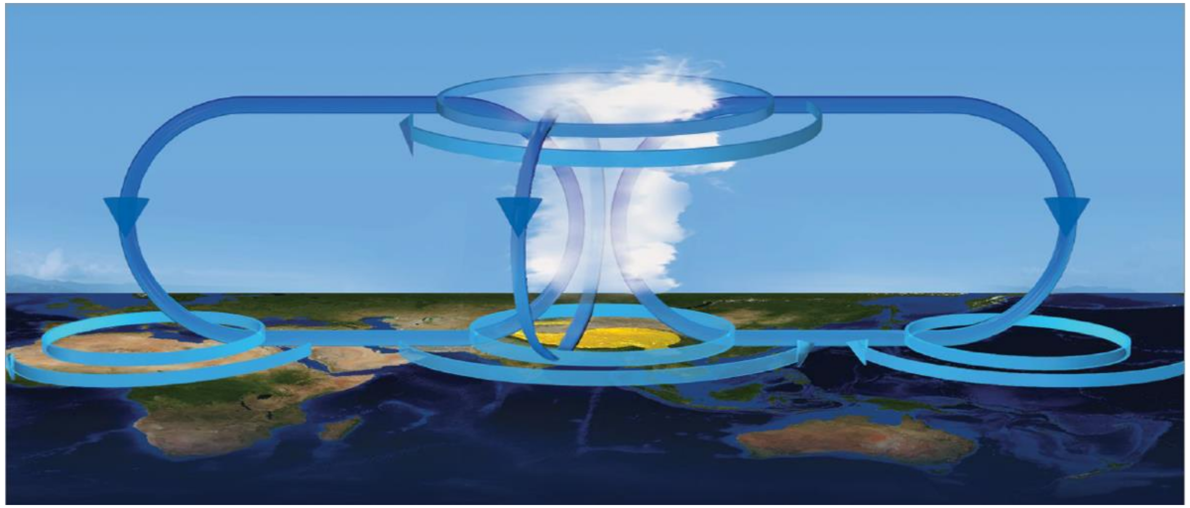


Honomichl and Pan (2020)
Backward trajectories initiated from the West Pacific High
(Proof-of-concept for the ACCLIP mission)

Air hitting 350K and below is part of sinking branches of Hadley-Walker circulation

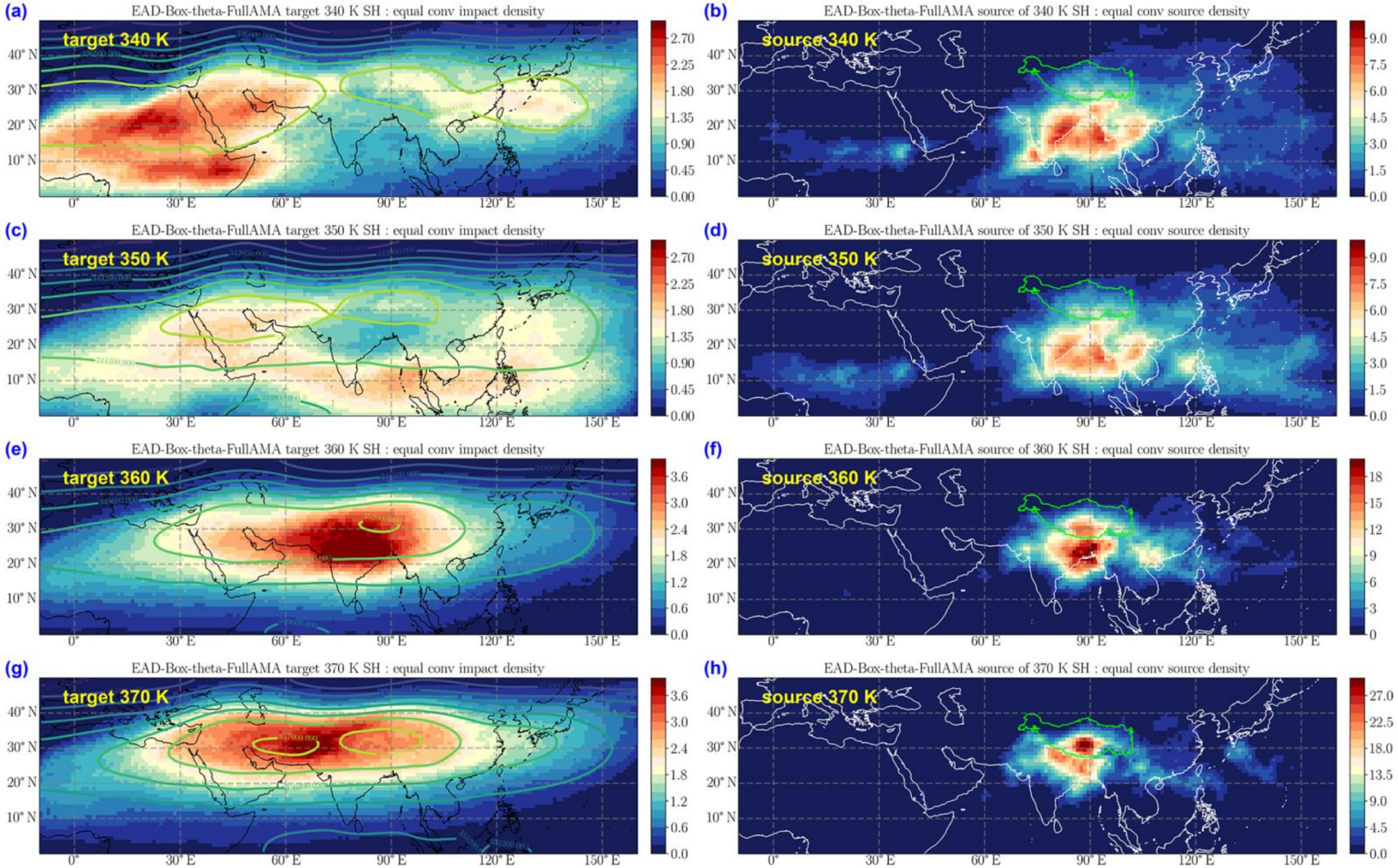


These air masses are mainly coastal and maritime in origin



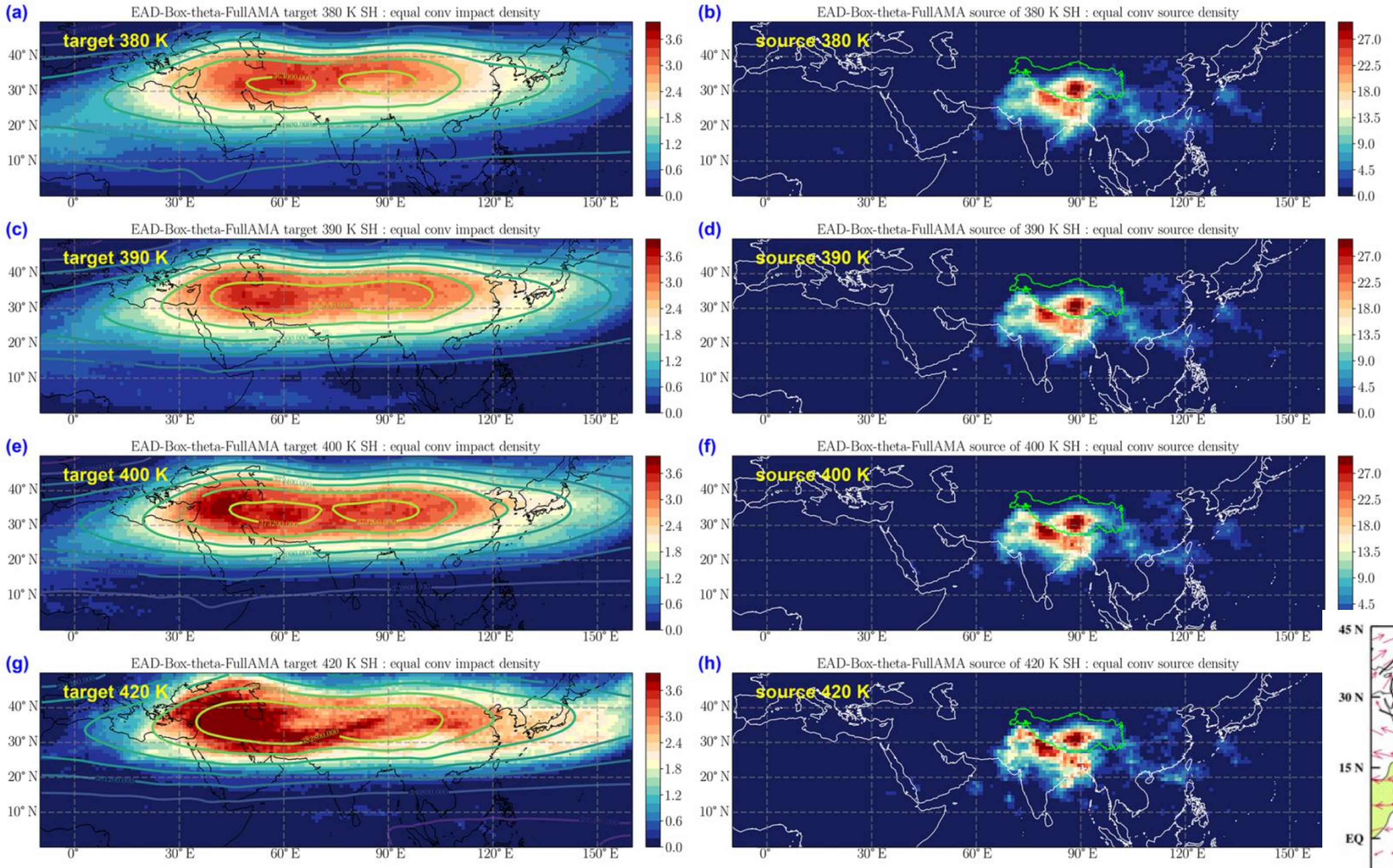
Credit: Zhang et al (2018)

At 360K and above, convective clouds deposit air masses into the confines of the ASMA

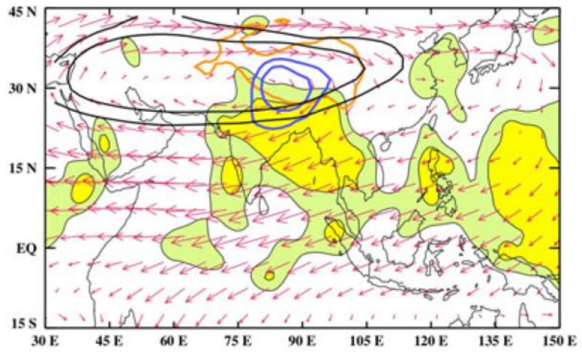


These air masses are biased toward continental origin

At 380K and above, convective impact retains a column shape which suggests a spiraling ascent (Vogel et al 2019)



The source regions are virtually identical and are consistent with the location of the "conduit" (Bergman et al 2013)



		Asia	Land	Ocean	Tibetan Plateau
All-sky LZRH	EAD	357.9 K	361.0 K	356.7 K	365.2 K
	EID	352.9 K	357.6 K	351.0 K	366.7 K
Crossover Level above which parcels preferentially ascend	EAD	363.9 K	364.4 K	362.5 K	364.2 K
	EID	361.7 K	361.8 K	358.5 K	363.1 K
High-cloud NWCSAF retrieval	Proportion	100 %	26.6 %	68.4 %	5.0 %
	Maximum high-cloud level	349.5 K	355.5 K	349.5 K	359.5 K
	Mean high-cloud level	352.9 K	356.4 K	351.1 K	359.0 K
High-cloud fraction above crossover	EAD	2.6 %	5.1 %	1.7 %	10.8 %
	EID	5.1 %	10.4 %	4.1 %	16.7 %
Impact at 380 K and above	EAD FullAMA	100 %	54.8 %	22.8 %	22.4 %
	EID FullAMA	100 %	54.4 %	32.0 %	13.6 %

The crossover is slightly higher than the LZRH, except over the Plateau

Convection is higher over land than ocean, and higher still over the Plateau

This yields a higher percentage of high clouds above the crossover over land

<u>The impact at 380 K thus favors continental sources</u>

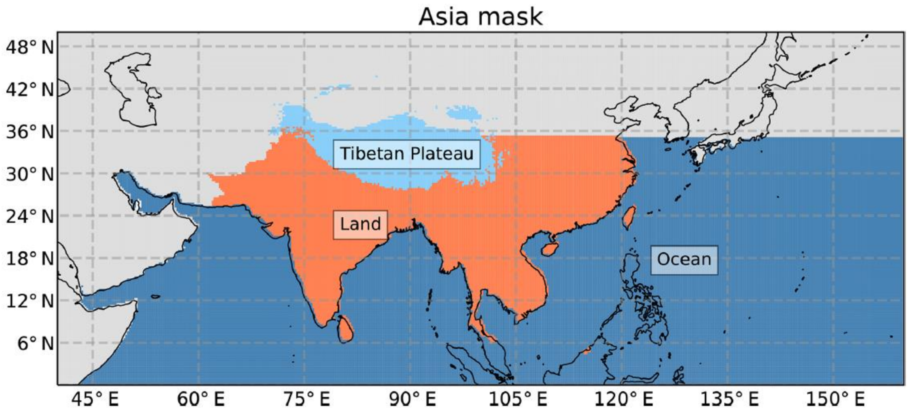
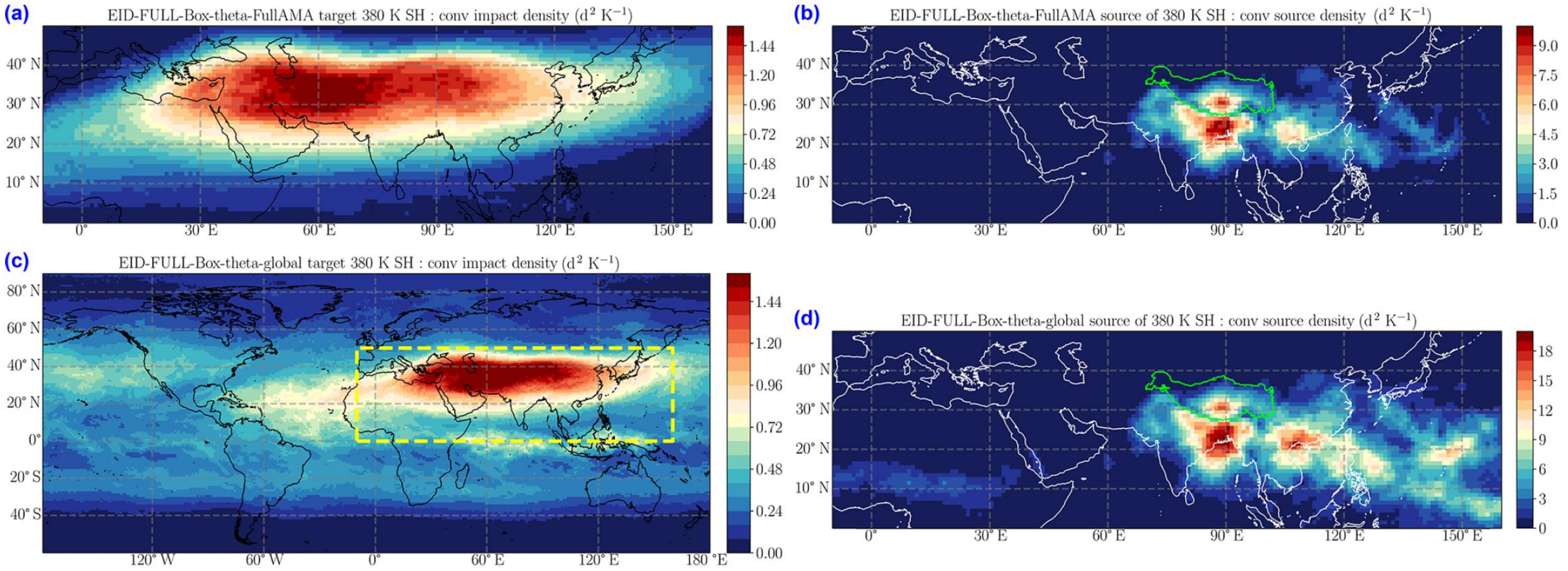
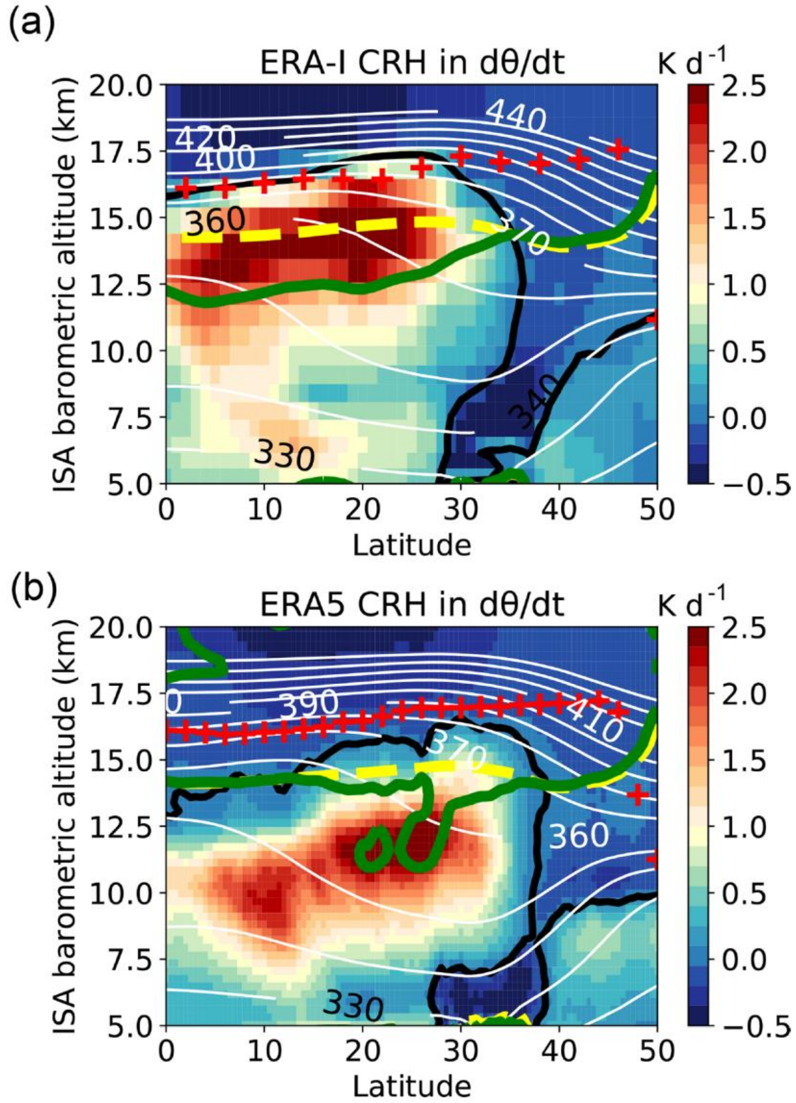


Figure 11. Mask of the three defined regions that partition Asia.

Expanding to a global domain enhances the contribution from maritime sources



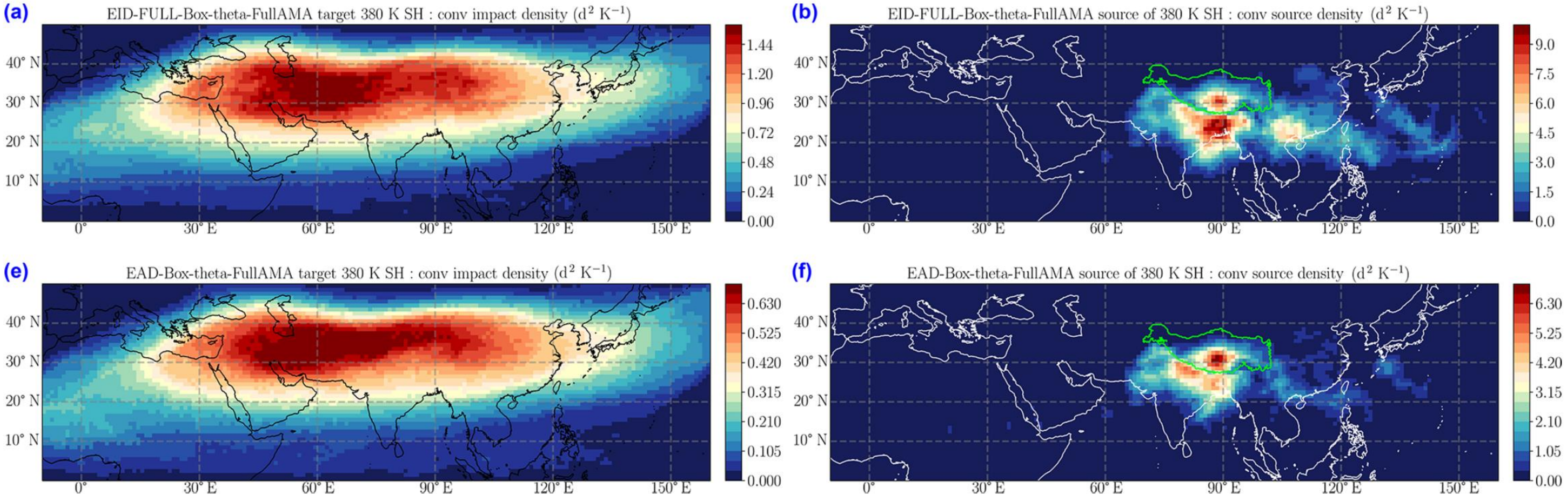
Question 3: How do the ERA-I and ERA5 reanalyses represent these processes?



Cloud-Radiative Heating is maximized higher in ERA-I, and more concentrated over land in ERA5

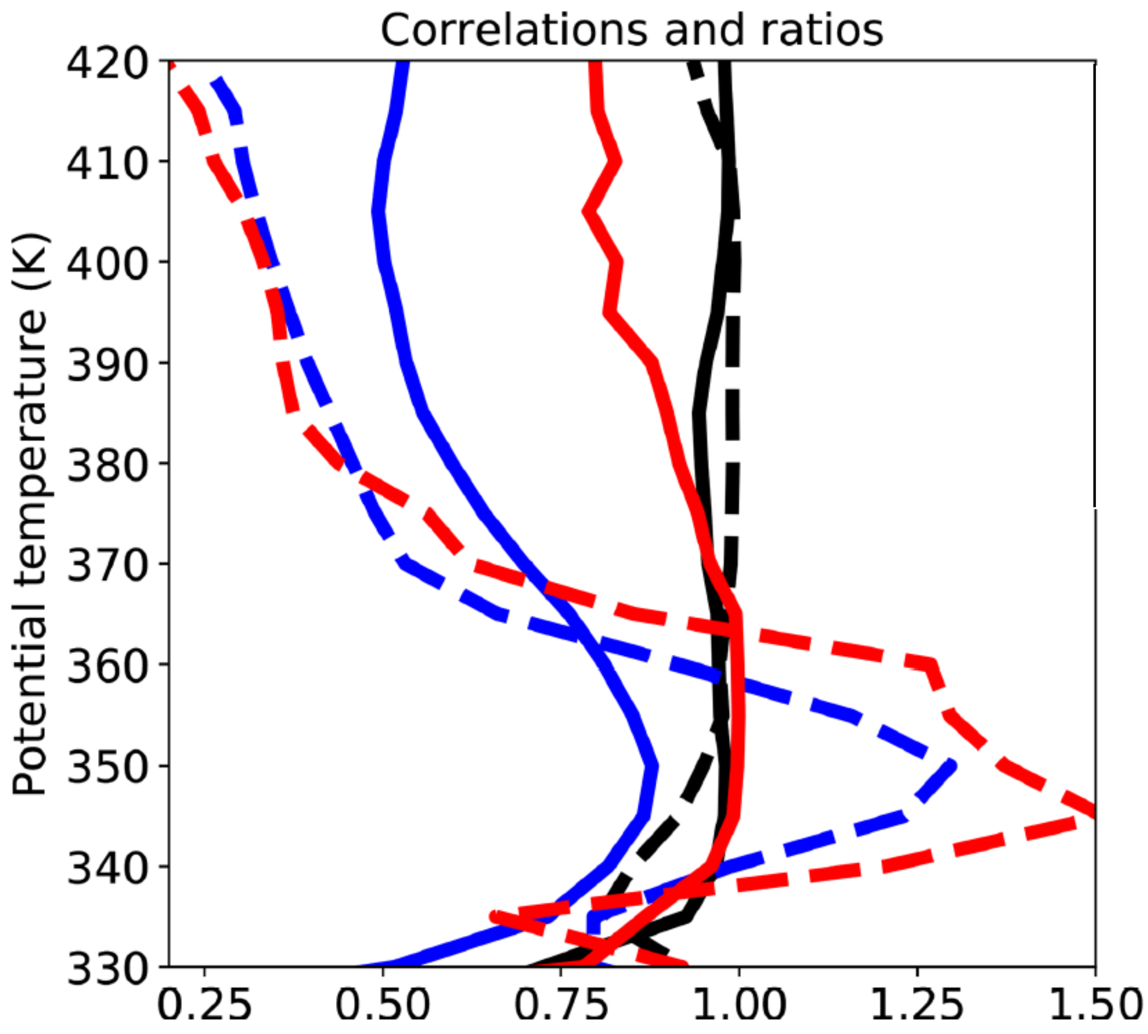
ERA5 has been shown to be most consistent with satellite observations (Tegtmeier et al 2020)

There is general qualitative agreement between the impact and source regions



There are some noteworthy differences on the southern Plateau slope and over the West Pacific

ERA-I and ERA5 correlate well but have some quantitative differences in impact

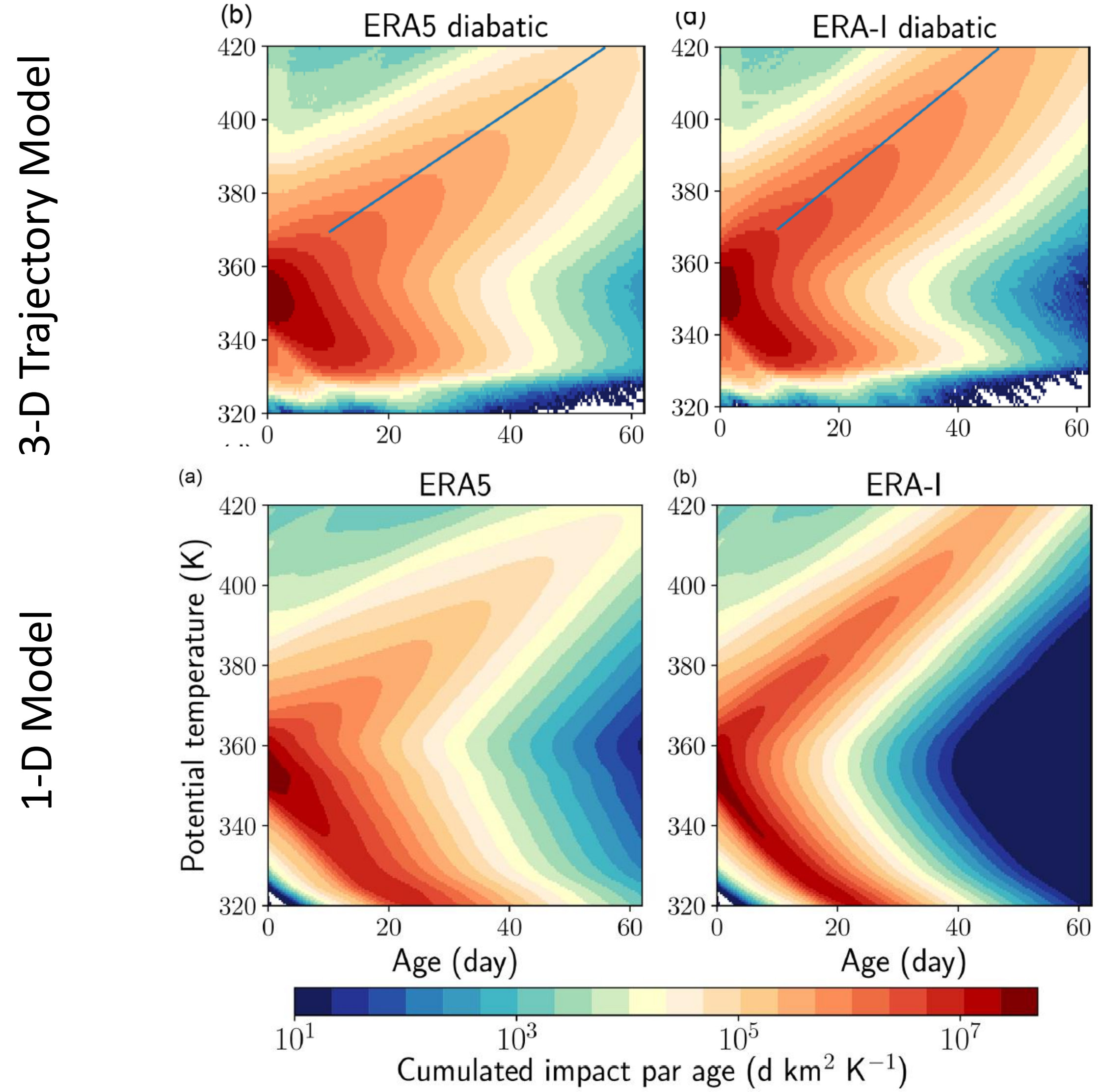


Red and blue lines are ratios between ERA-I and ERA5

Dashed shows ERA-I vs ERA5, Solid shows impacts of a global vs restricted trajectory domain

Black lines are their correlations

A 1-D confinement model produces adequate representation of ASM behavior



$$\frac{\partial F}{\partial t} + \frac{\partial \dot{\theta} F}{\partial \theta} = -\frac{1}{\alpha} F + \kappa \frac{\partial^2 F}{\partial \theta^2} + S(\theta)$$

The equation considers:

- Diffusion
- Attenuation at the boundaries
- The vertical distribution of sources
  (the exponential decay of cloud tops with altitude)

The 1-D model is representative of the confinement of parcels within the anticyclone!

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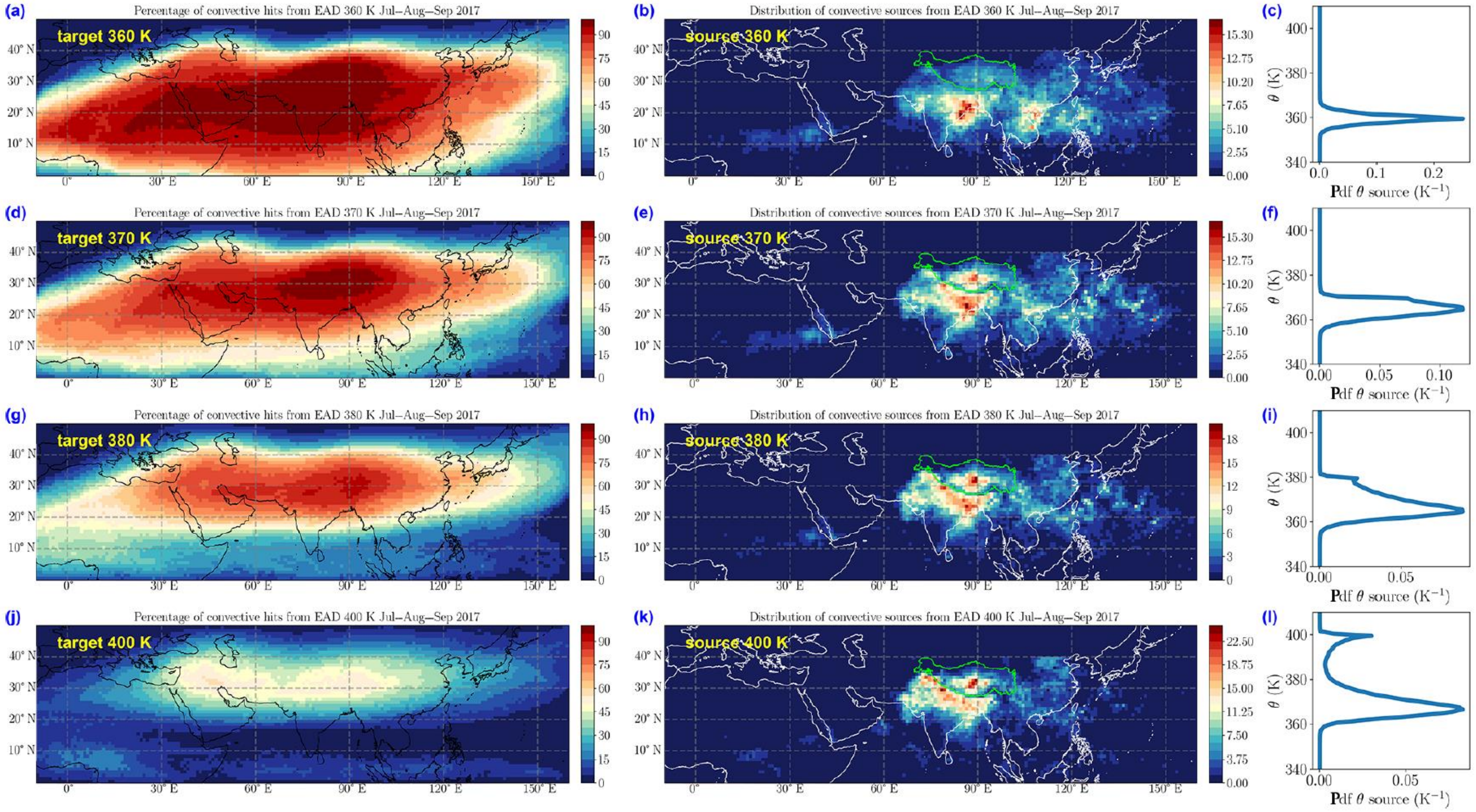
Question 3: How do different reanalyses represent these processes?

- ERA-I and ERA5 are qualitatively similar but quantitatively differ. ERA5 is more consistent between kinematic and diabatic trajectories than ERA-I


(a)
Percentage of convective hits from EAD 360 K Jul–Aug–Sep 2017
target 360 K
(b)
Distribution of convective sources from EAD 360 K Jul–Aug–Sep 2017
source 360 K
(c)
(d)
Percentage of convective hits from EAD 370 K Jul–Aug–Sep 2017
target 370 K
(e)
Distribution of convective sources from EAD 370 K Jul–Aug–Sep 2017
source 370 K
(f)
(g)
Percentage of convective hits from EAD 380 K Jul–Aug–Sep 2017
target 380 K
(h)
Distribution of convective sources from EAD 380 K Jul–Aug–Sep 2017
source 380 K
(i)
(j)
Percentage of convective hits from EAD 400 K Jul–Aug–Sep 2017
target 400 K
(k)
Distribution of convective sources from EAD 400 K Jul–Aug–Sep 2017
source 400 K
(l)
θ (K)
Pdf θ source (K⁻¹)