The confinement of air in the Asian Monsoon Anticyclone and transport across the Tropical Tropopause Layer

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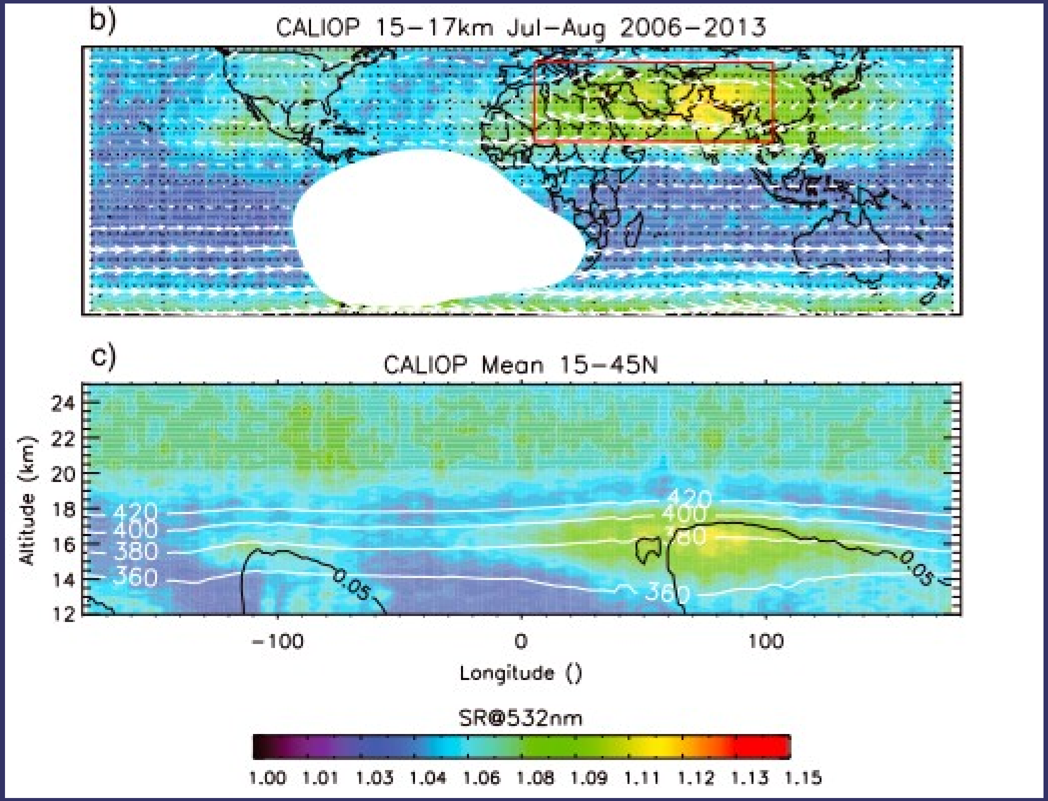
Motivation :

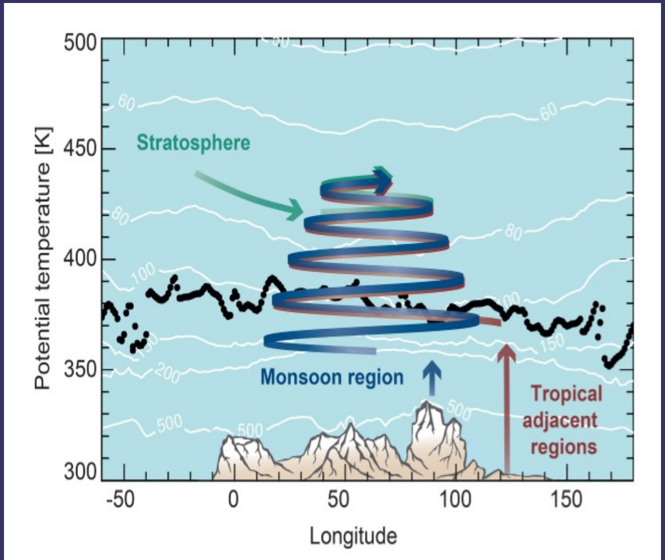
How the Asian Tropical Aerosol Layer can be generated by trapping the continental Asia ground emissions within the Asian Monsoon Anticyclone

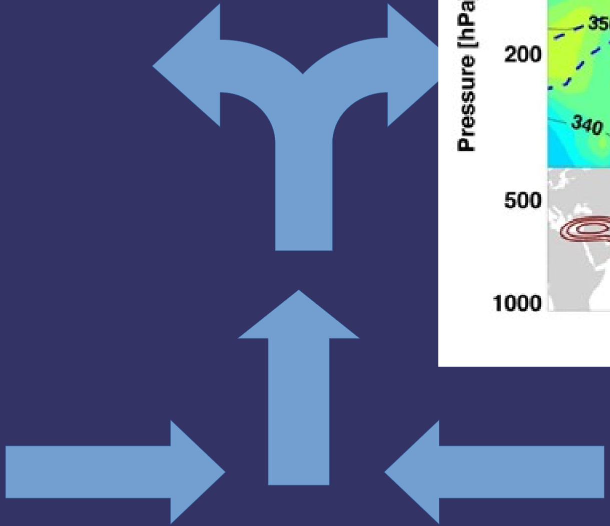
More generally : what are the pathways to the stratosphere across the Tropical Tropical Layer during sumer and what is the respective contribution of continental versus oceanic sources.

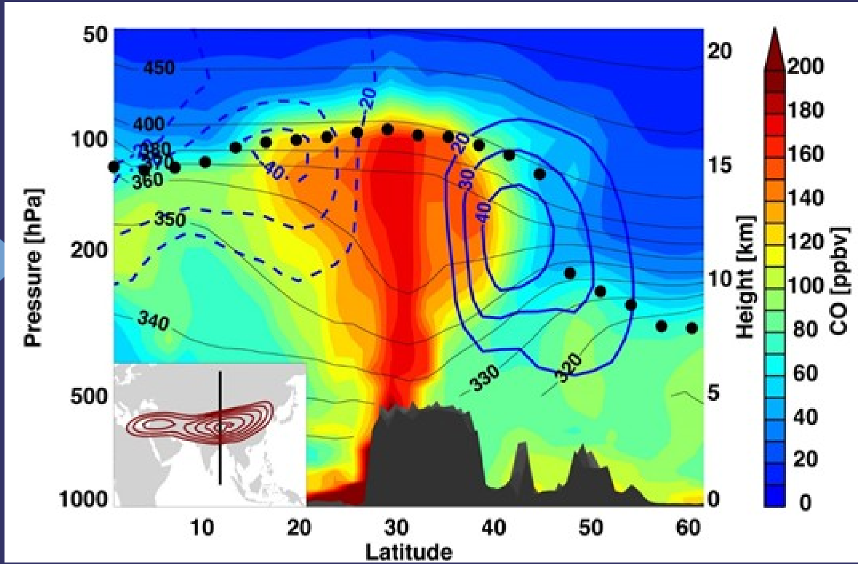


Vernier et al., JGR, 2015

Broad spiraling ascent or narrow conduit above the Tibetan Plateau







Voget et al, ACP, 2019

Tissier & Legras, 2016

Pan et al, JGR, 2016

Bergmann et a, JGR, 2015

Method : Lagrangian forward and backward trajectories from and to clouds

Using

- ERA5 : 0.25°, 137 levels, hourly in the FullAMA domain, diabatic & kinematic trajectories

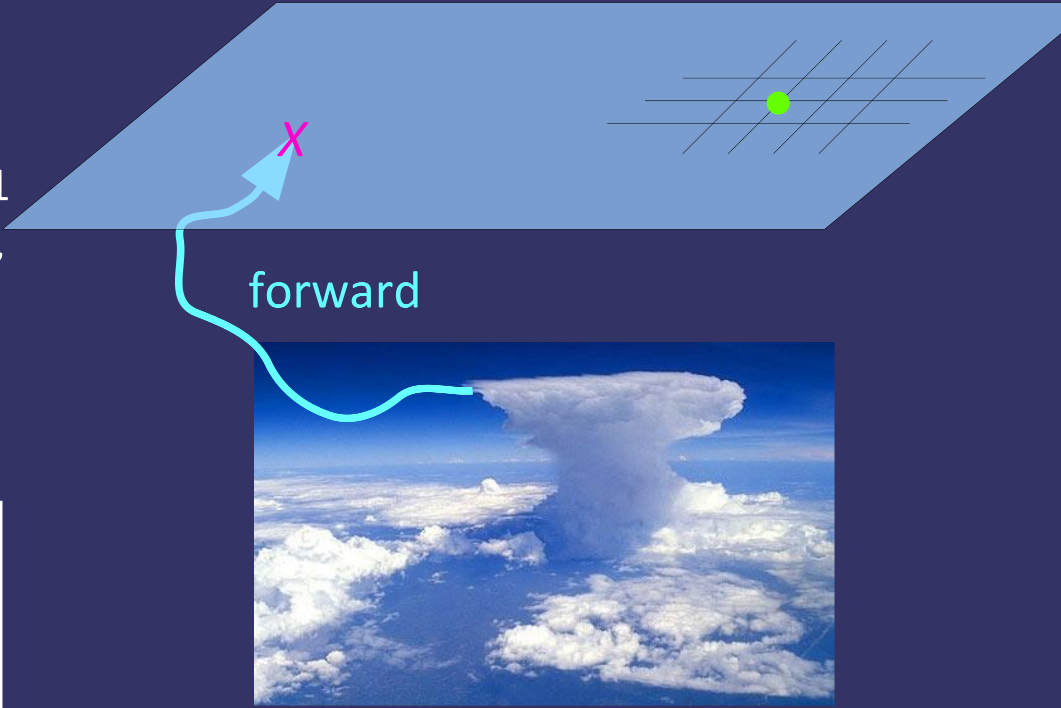
(+ ERA-Interim for comparison)

Clouds characterized by

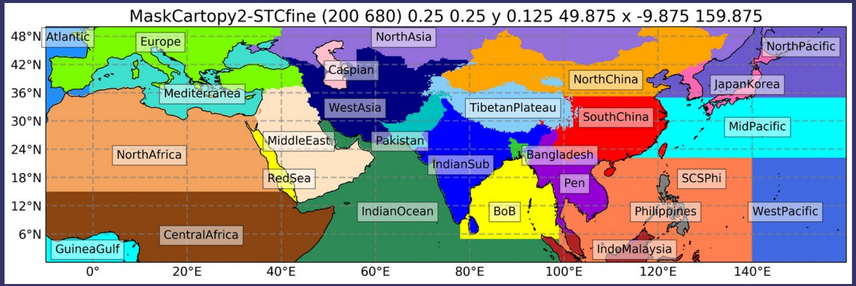
- SAFNWC/Eumetsat cloud top altitude from MSG1 (45.5E) and Himawari 8 (140E) (Derrien & Le Gléau, I. J. Remote Sensing, 2010) [improved from operational product]

Summer 2017

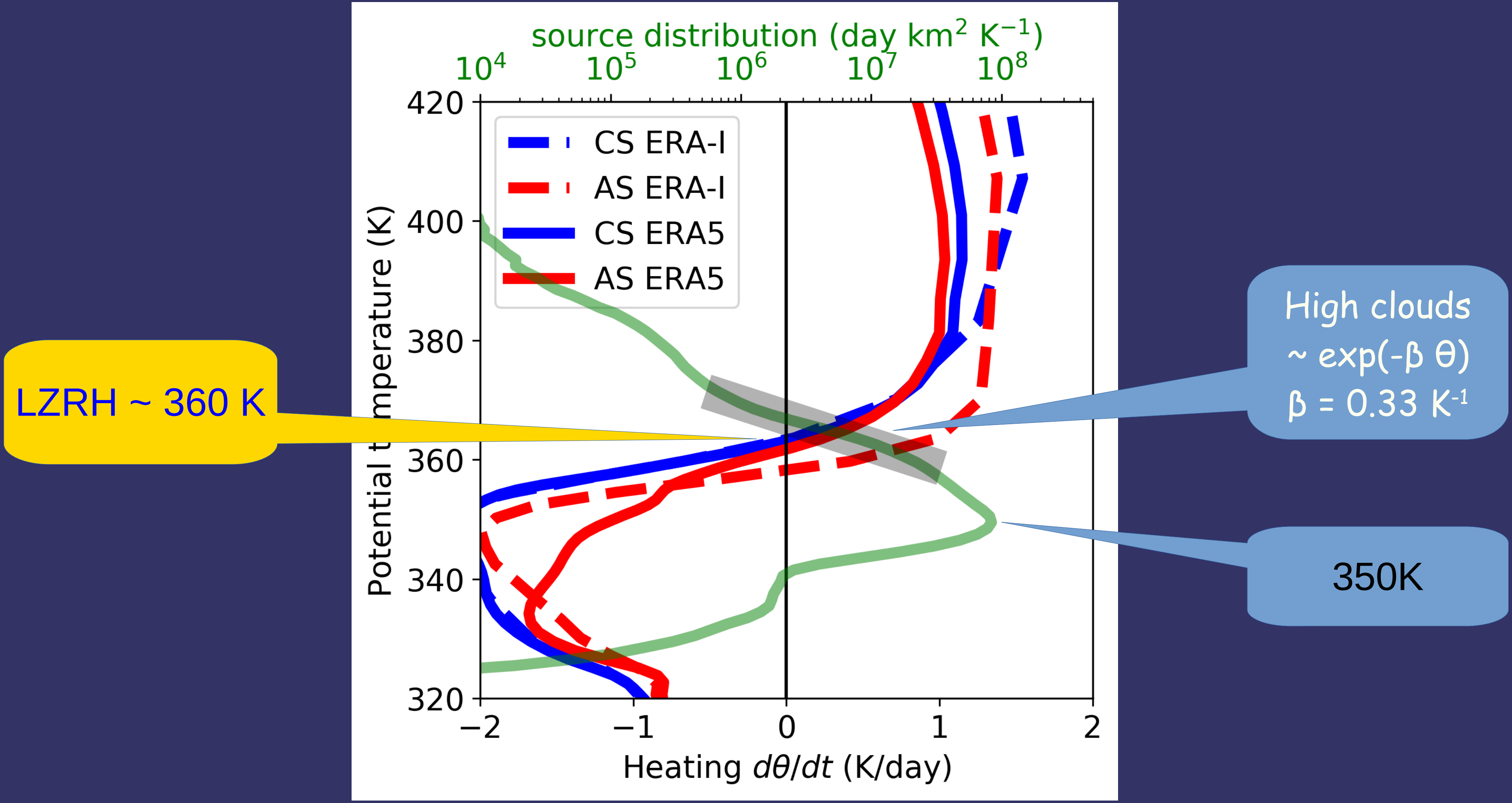
Isobaric or isentropic surface



The Full AMA domain



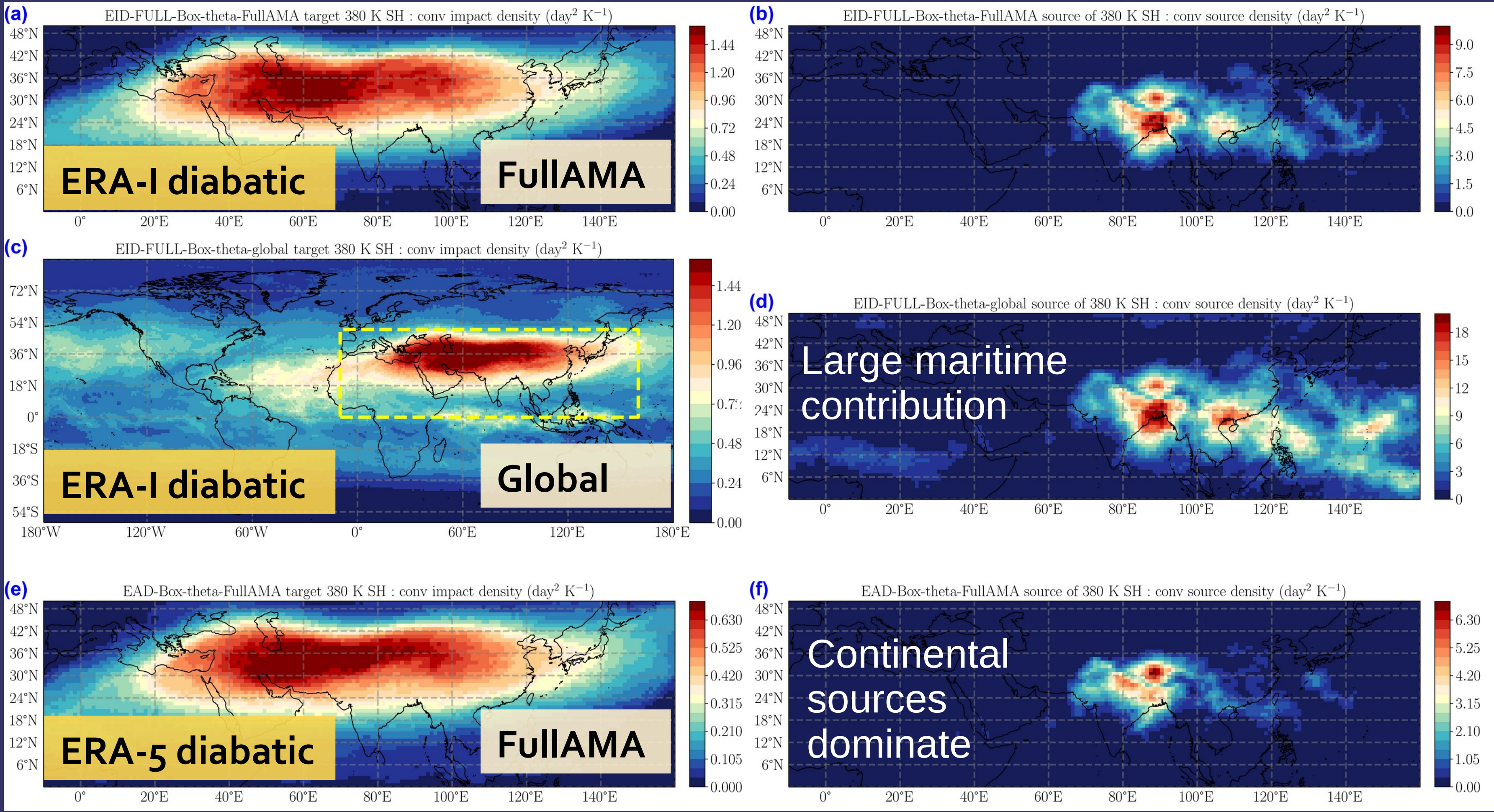
Vertical distribution of sources
And heating rates



380K impact – target

FORWARD

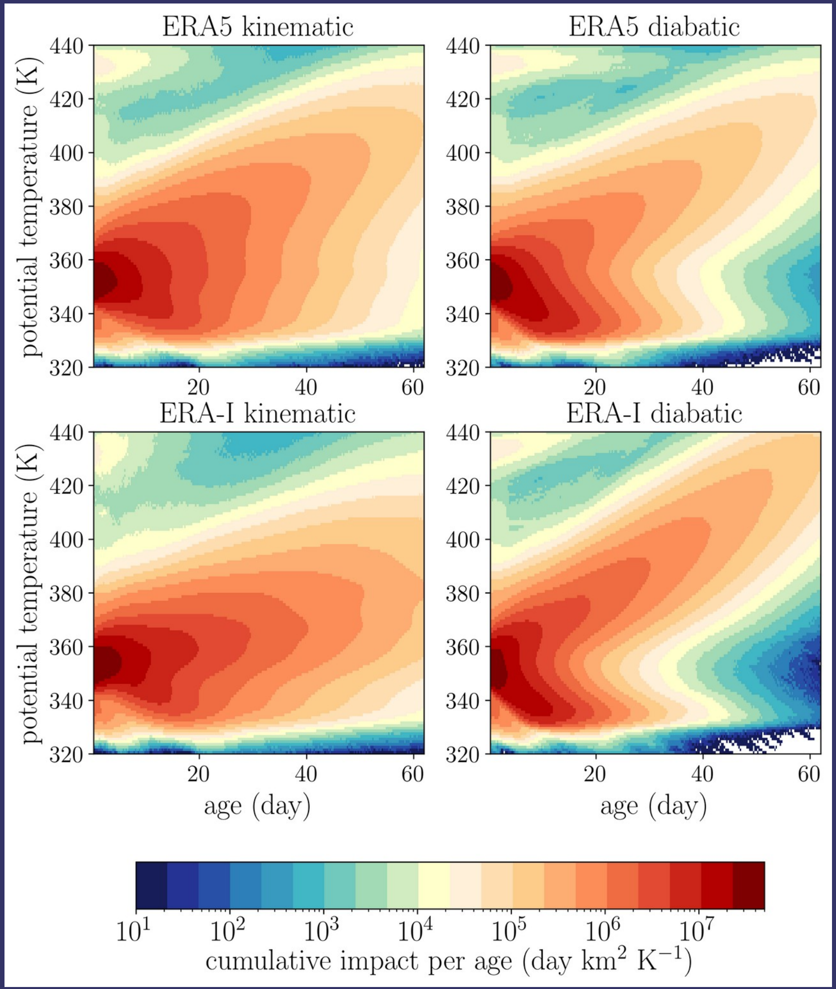
380K impact – source



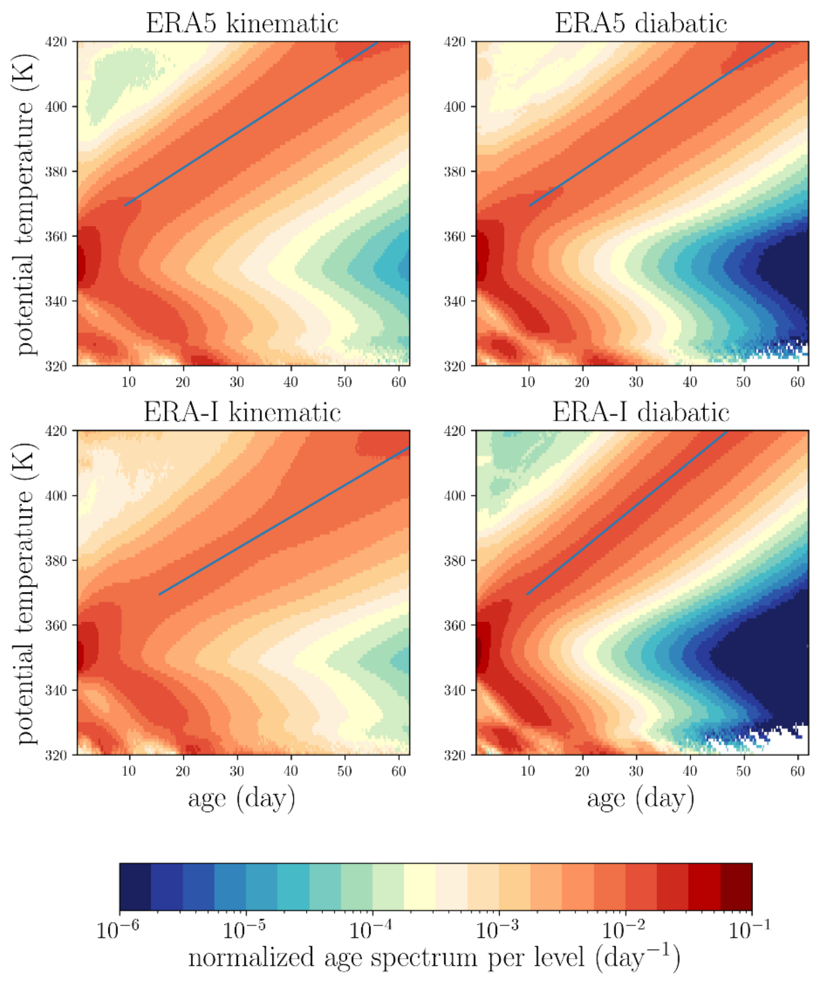
FORWARD

Vertical propagation of the impact in the FullAMA domain as a function of the age with respect to convective injection.

From the main source level, the convective impact in the FullAMA domain propagates both upward and downward as a function of age, and exhibits damping as parcels leave the domain by horizontal motion.



Vertical propagation of normalized impact



Slope A (K/day)	Kinematic	Diabatic
ERA5	1.08	1.11
ERA Interim	0.97	1.35

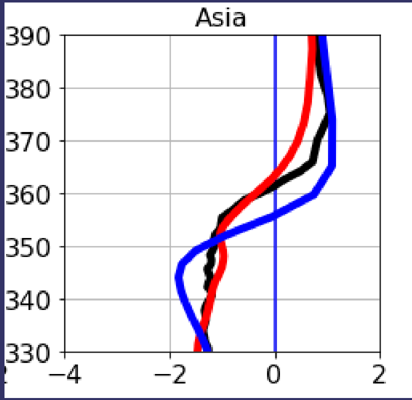
Faster ------------------------------------ Slower

ERA-I diab > ERA5 diab ≈ ERA5 kin > ERA-I kin

Retained value dΘ/dt = 1.1 K/day over 370 – 420 K

All sky heating rate dΘ/dt (K/day)

Ascent
A = 1.1 K/day



ERA5
ERA-I
FLXHR

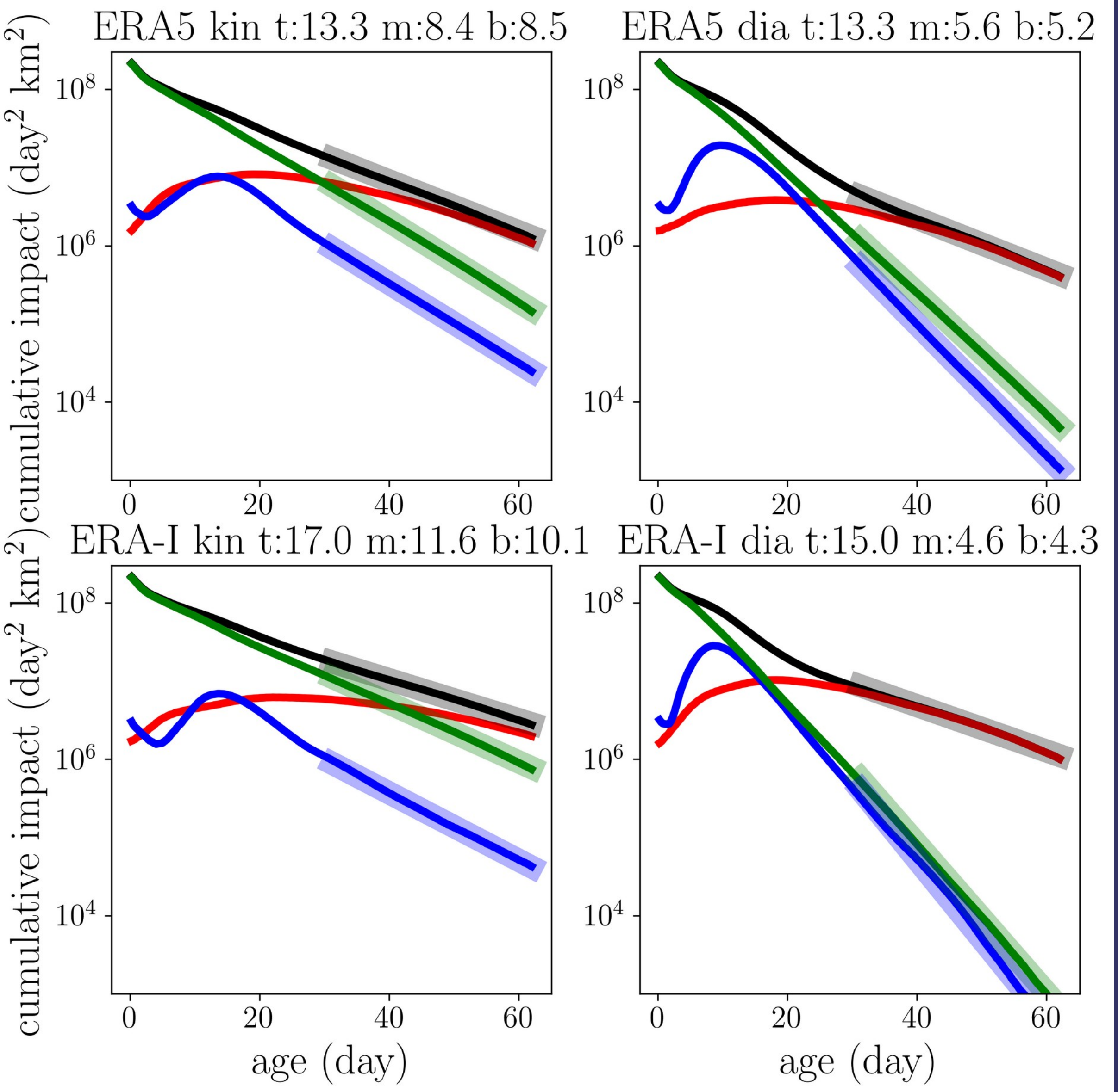
Escape rate of the FullAMA domain

The escape time τ is estimated from the decay rate of the impact

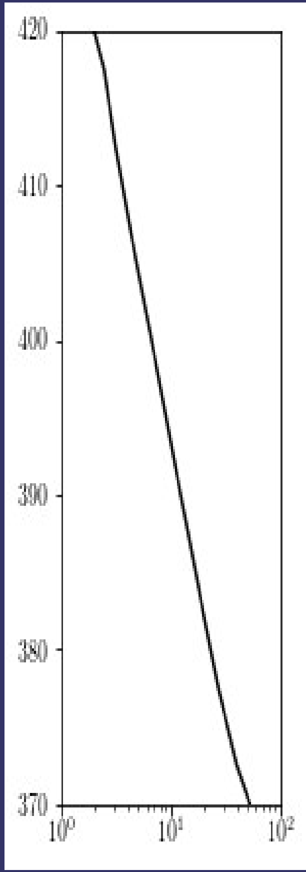
We find a good consensus of ERA5 kinematic and diabatic at
τ = 13.3 days

Loss
τ = 13.3 day⁻¹

Total
ϴ < 340K
340K < ϴ < 370K
370K < ϴ



Magnitude



Exp(-Δθ/χ)

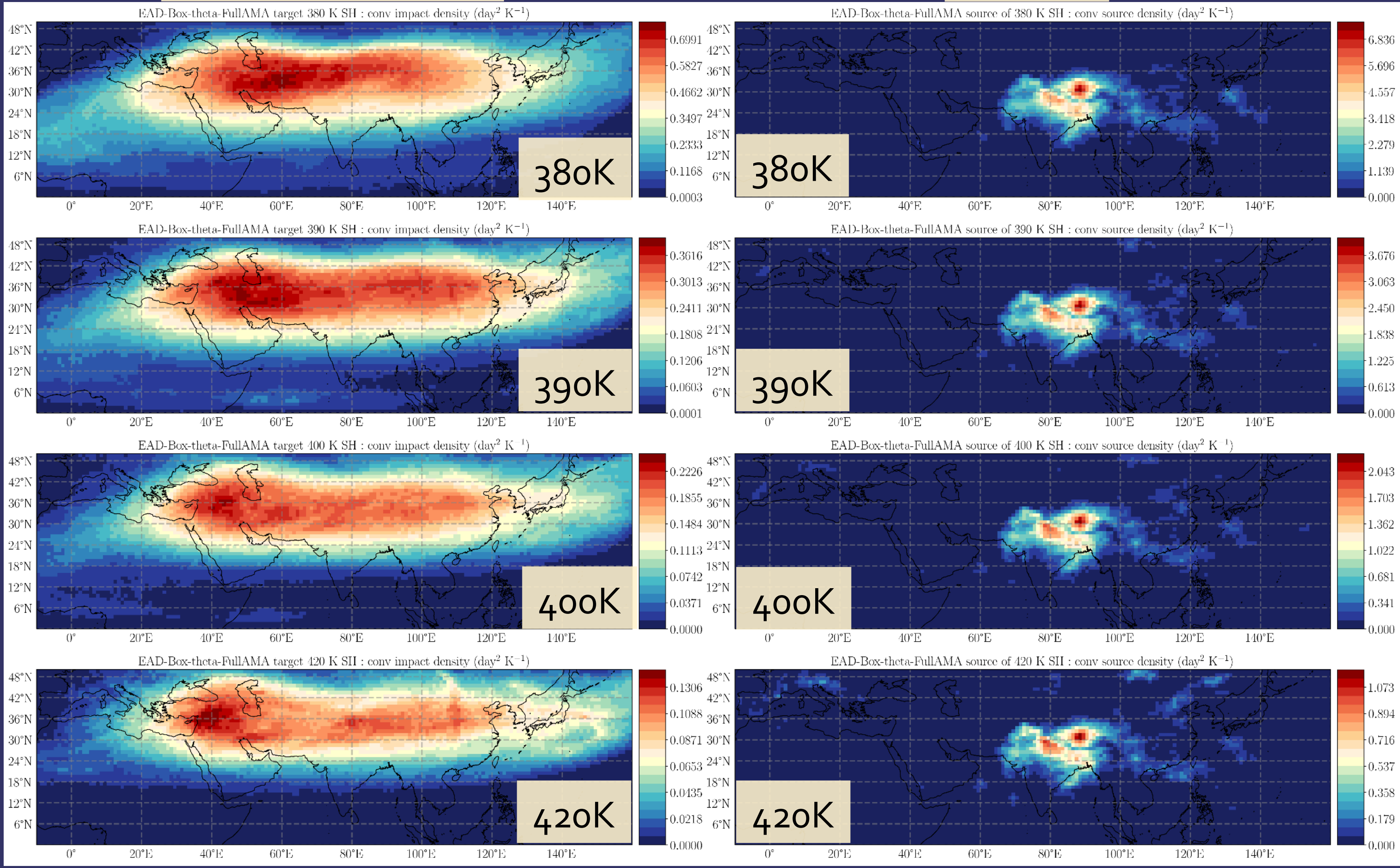
χ= 16 K

Predicted A τ =15 K

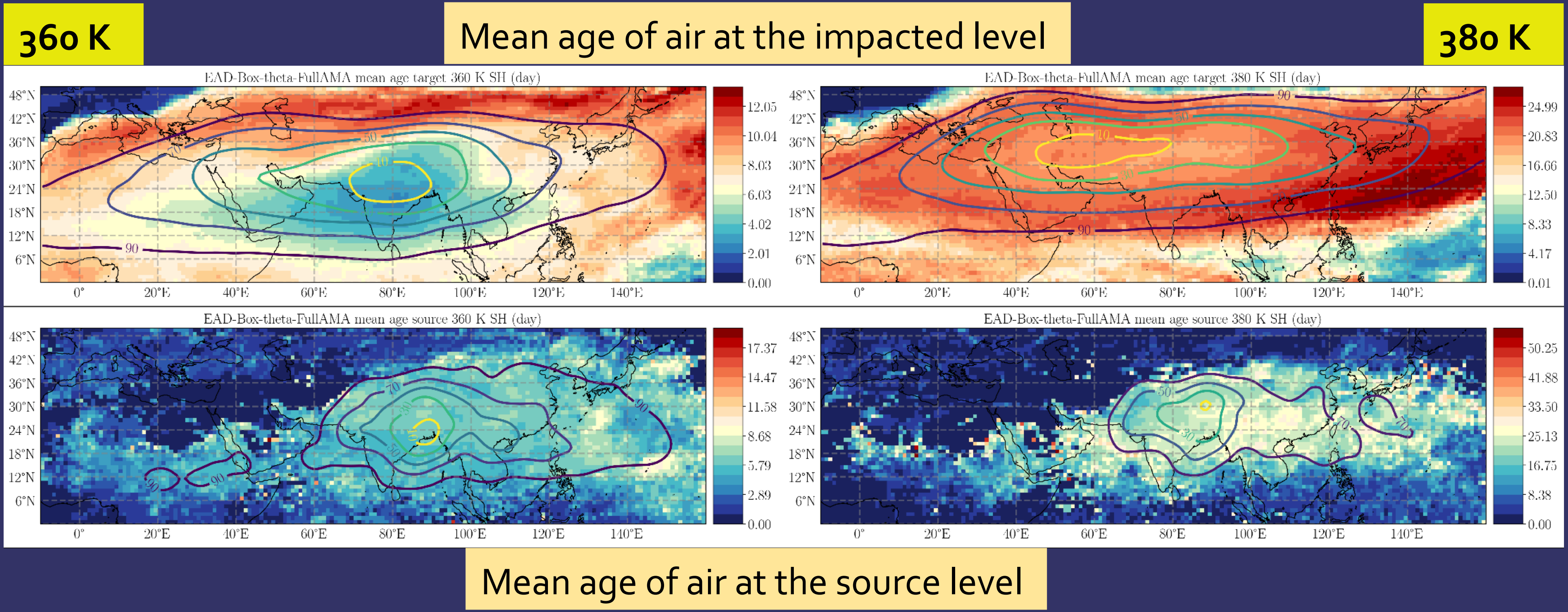
Convective impact

FORWARD

Sources



FORWARD



The age of air is minimun at the centre of the confined region and maximum at its periphery -> result of competition between renewal and escape.

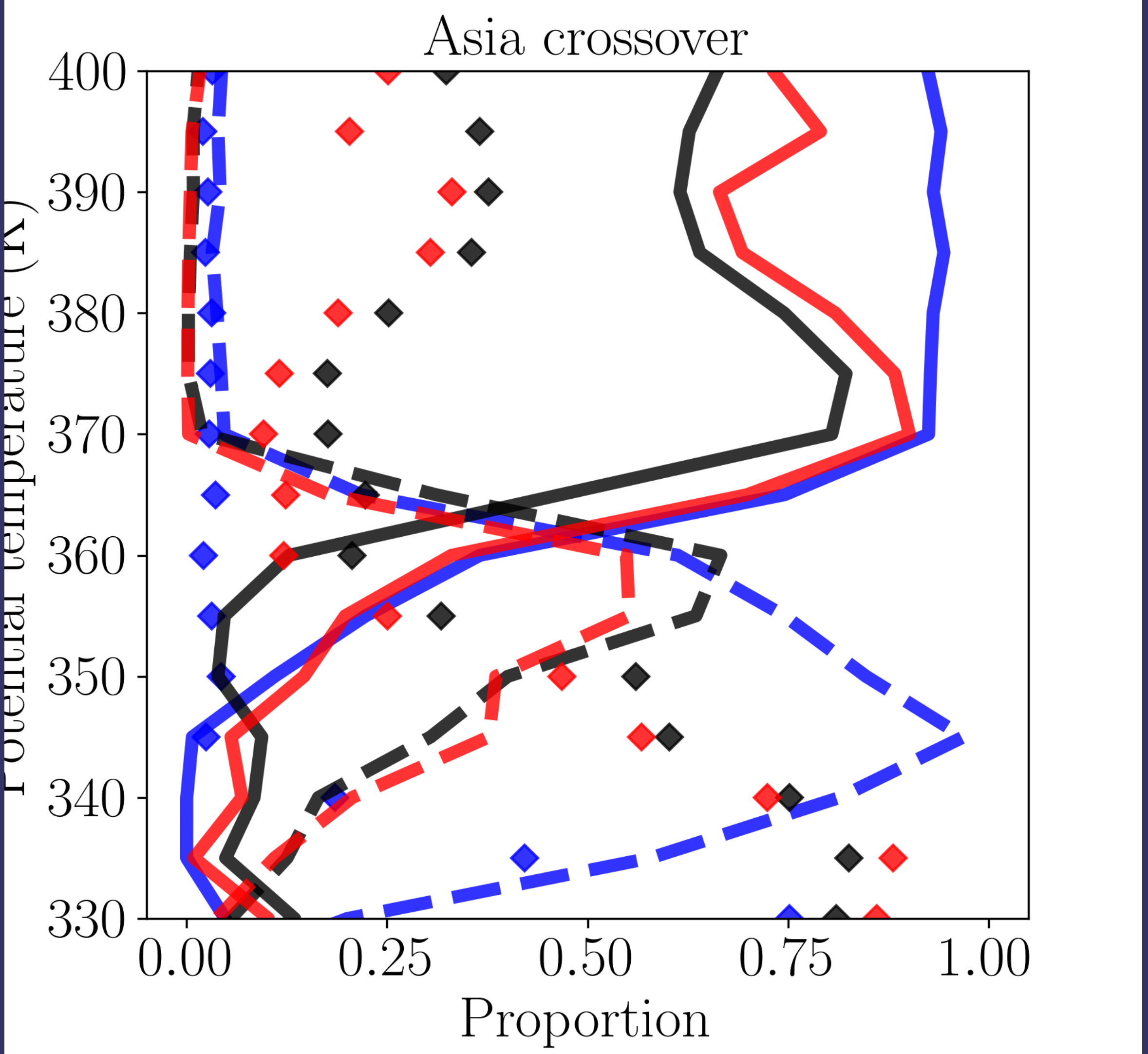
In the source domain, the age of air has no pattern associated with the Tibetan plateau -> the air from this region does not tend to reside more than the air from other sources in the AMA

Crossover ascending / descending over Asia

ERA5	ERA-I
363.9 K	361.7 K

Solid: proportion going upward
Dash: proportion going downward
Dots: proportion staying within 2.5 K

ERA5 diab in FullAMA domain
ERA-I diab in FullAMA domain
ERA-I diab in global domain



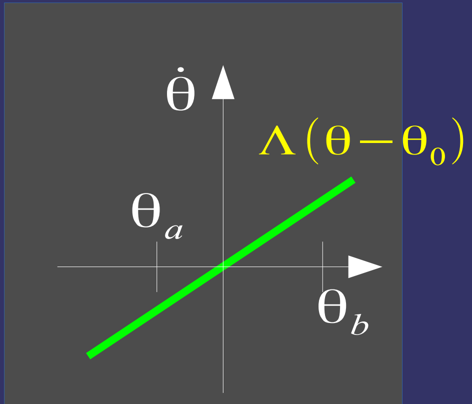
ASIA = OCEAN + LAND + Tibetan Plateau

Contributions to the ascending trajectories above the crossover

	Asia	Land	Ocean	Tibet
High clouds (SAF)	100 %	26.6 %	68.4 %	5 %
Maximum of high clouds (SAF)	349.5 K	355.5 K	349.5 K	359.5 K
All sky LZRH (ERA5)	357.9 K	361.4 K	356.7 K	365.2 K
Up/down crossover	363.9 K	364.4 K	362.5 K	364.2 K
Full AMA impact > 380K ERA5 ERA-I	100 %	54.8 % 54.4%	22.8 % 32%	22.4 % 13.6 %
World impact > 380K	100%	39.0 %	52.9 %	8.1 %
High cloud > crossover ERA5 ERA-I	2.6 % 5.1 %	5.1 % 10.4 %	1.7 % 4.1 %	10.8 % 16.7 %

The confinement of Asia Land and the Tibetan plateau can be fully explained by the higher proportion of convective tops above the crossover level.

A simple leaky advective-diffusive model



Above 360 K, the transport in the AMA region can be interpreted with a simple model of transport-diffusion with loss, that is

$$\frac{\partial F}{\partial t}+\frac{\partial \dot{\theta} F}{\partial \theta}=\frac{\partial}{\partial \theta} K \frac{\partial F}{\partial \theta}-\alpha F+S(\theta,t)$$

where α^{-1} is about 13.3 days and $\dot{\theta}$ is about 1.1 K/day.

In the simplest case, when $\dot{\theta}=\Lambda(\theta-\theta_0)$ and $\alpha=0$ the 1D model is a Fokker-Planck equation and the transit probability from θ_a to θ_b is ¿ $\Pi(\theta_a,\theta_b)=\frac{1+erf(\nu(\theta_a-\theta_0))}{1+erf(\nu(\theta_b-\theta_0))}$

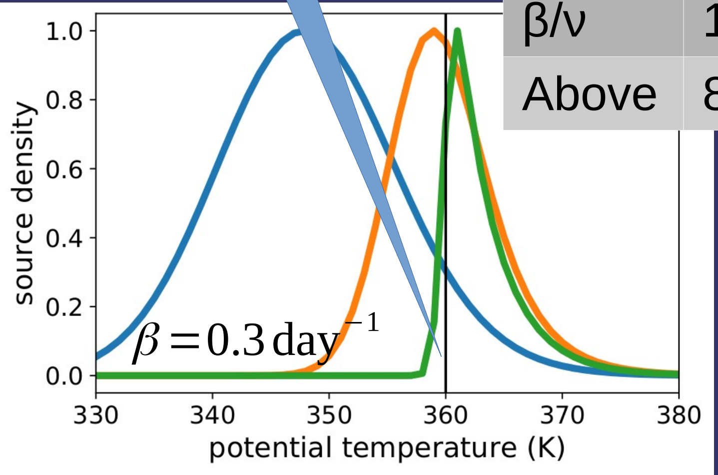
with $\nu=\sqrt{\Lambda 2 \kappa}$

Detrainment level of clouds

Assuming an exponential distribution of convective detrainment ~ $e^{-\beta(\theta - \grave{u}theta_0)}$,
the distribution of convective sources that impact a given level is

$$P(\theta) = N^{-1} e^{-\beta(\theta-\theta_0)} \left(1 + erf\left(\nu(\theta-\theta_0)\right)\right)$$

LZRH



β/ν	1/3	2/3	3
Above	8 %	50 %	97 %

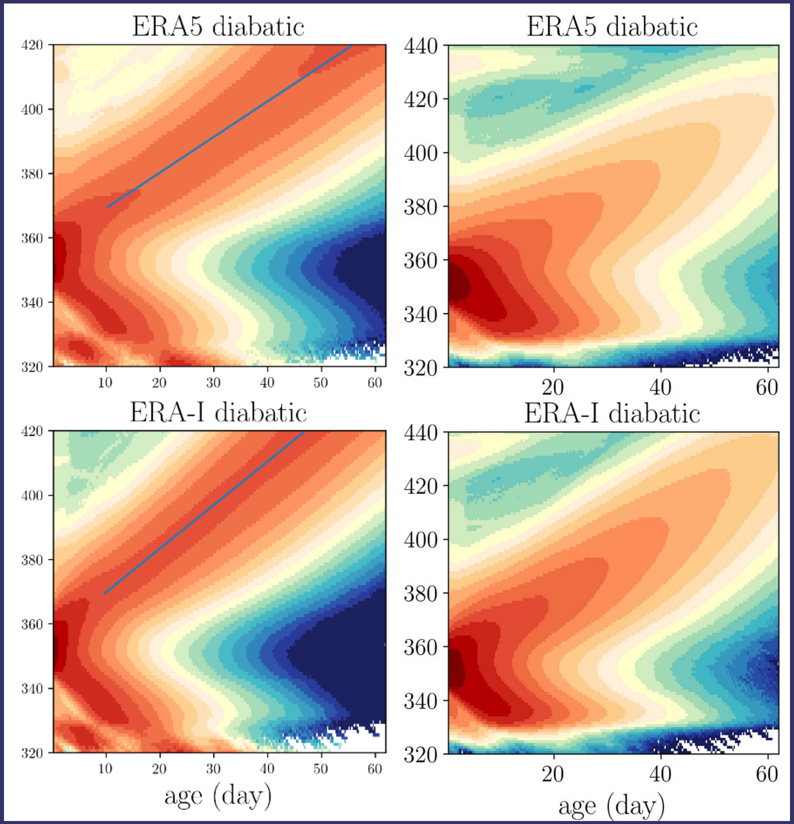
Proportion of sources above the LZRH

	Asia	Land	Ocean	Tibet
ERA5 AMA	95.3 %	83.6 %	96 %	35.3 %
ERA-I AMA	96 %	87.6 %	95.6 %	14.4 %
ERA-I global	75.8 %	74.9 %	81.8 %	12.7 %

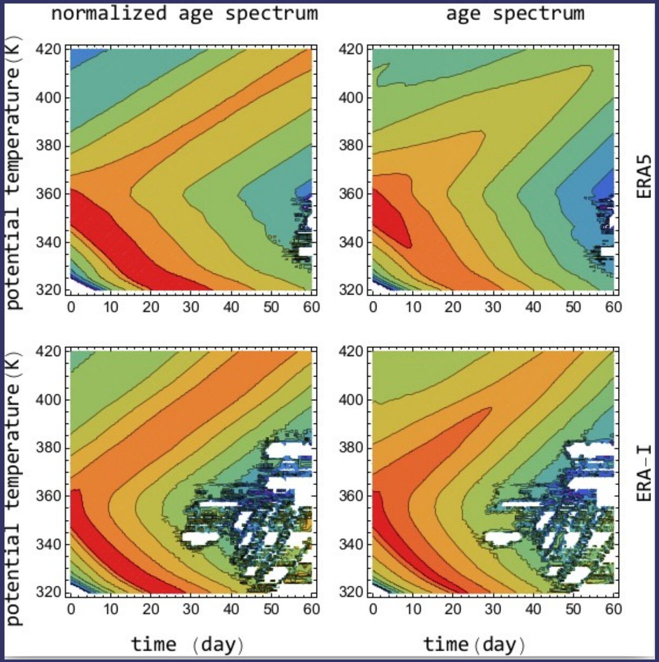
According to the ratio β/ν, convective sources are below $(\beta/\nu < 2/3)$ or above $(\beta/\nu > 2/3)$ the LZRH

Integrating the 1D model with heating rates from reanalysis and observed (SAFNWC) distribution of clouds (no diffusion)

Normalized | Non normalized

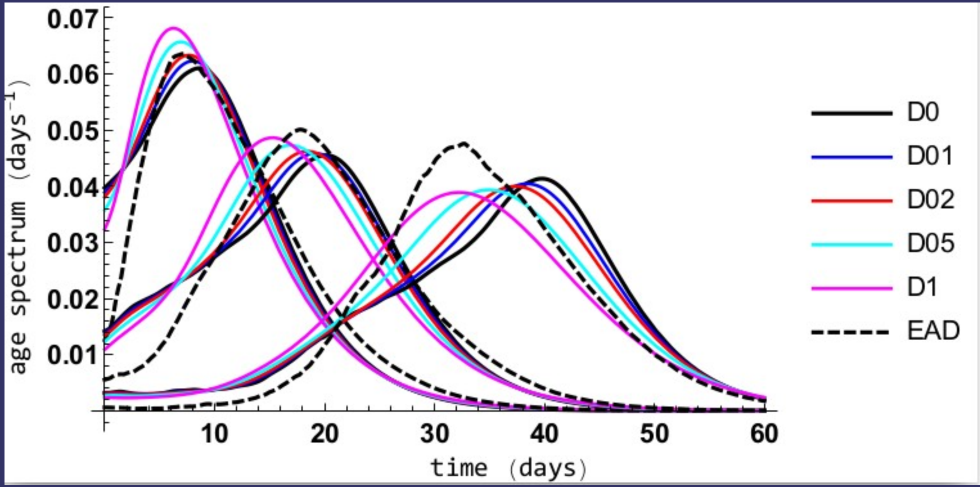


Full 3D calculations



1D model

Normalized impact at 3 levels 370 K, 380 K and 400 K
ERA5 3D calculation and 1D model with diffusion



	Land	Ocean	TP
High clouds	27 %	68 %	5 %
AMA impact	55 %	23 %	22 %
Global impact	39 %	53 %	8 %