Age of air / convection

Confinement of convective air in the Asian Monsoon Anticyclone and transport across the TTL

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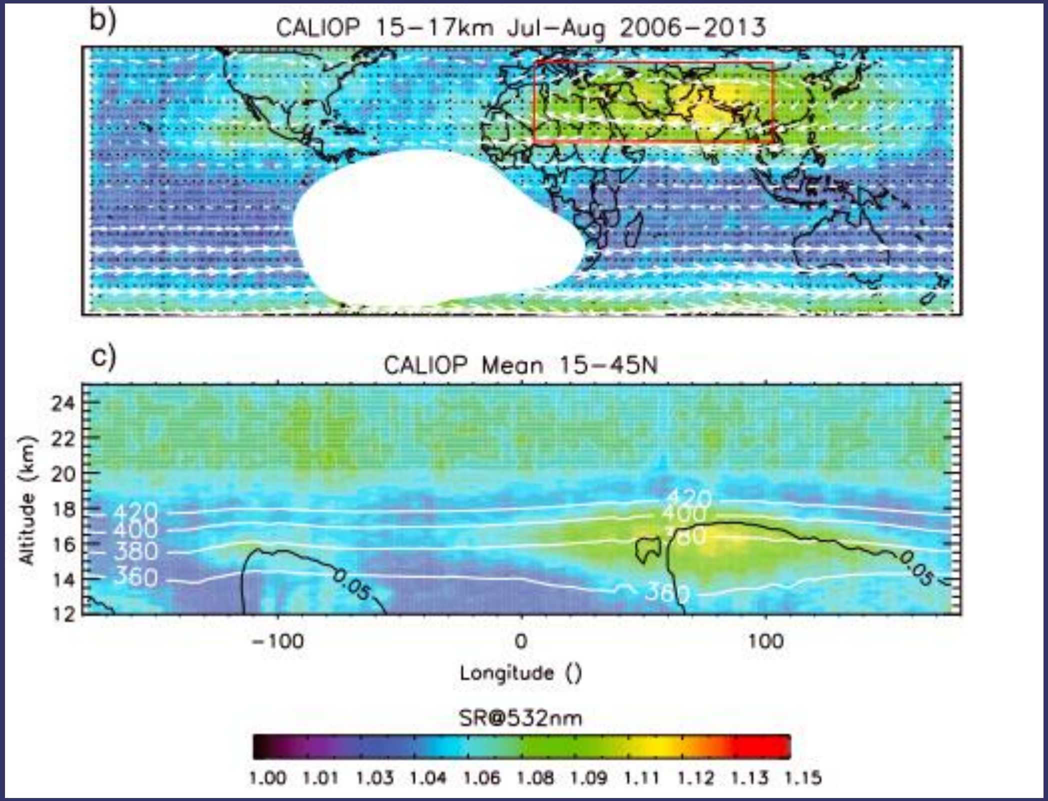
Supported by StratoClim, EU FP7 603557 and CEFIPRA grant 5607-C

PROES meeting, 22-23 October 2018, Paris

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.



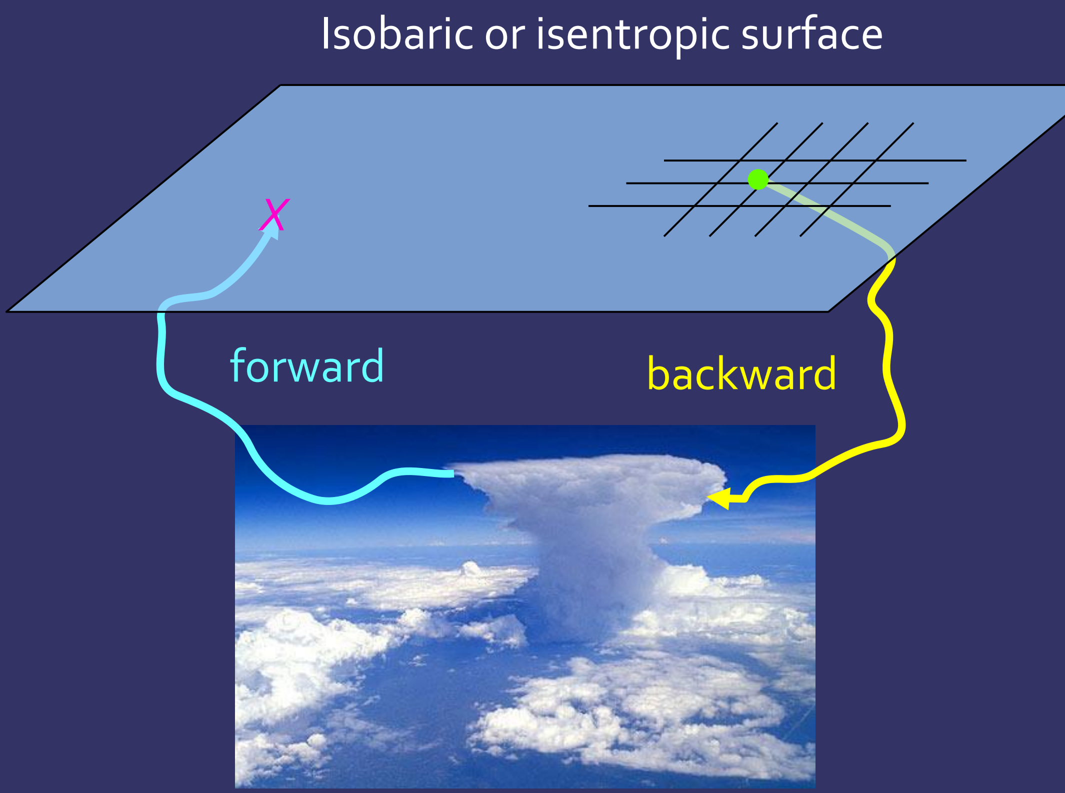
Vernier et al., JGR, 2015

Method : Lagrangian forward and backward trajectories from and to clouds

Using
ERA5 : 0.25°x0.25°, 137 levels, hourly
in the AMA domain 10W-160E, 0-50N
ERA-Interim : 1°x1°, 60 levels, 3-hourly
in the AMA and global domain

Both kinematic and diabatic trajectories with TRACZILLA (Pisso & Legras, 2008)

Clouds characterized by
- SAFNWC/Eumetsat cloud top altitude from MSG1 and Himawari (Derrien & Le Gléau, 2010) [improved operational product]
- Detrainement rate from ERA5
- Notice : Clouds limited to the AMA domain !



Transport of the χ substance

From the transport equation

$$\frac{\partial \phi}{\partial t} + u.\nabla\phi = \frac{1}{\rho}\nabla K\rho\nabla\phi + \alpha(\phi_c - \phi)$$

with α= cloud detrainement rate, and ϕ_c= tracer mixing ratio in detrained air,
we define the adjoint equation for χ

$$\frac{\partial \chi}{\partial t} + u.\nabla\phi = \frac{-1}{\rho}\nabla K\rho\nabla\phi - \alpha\chi$$

which can be integrated backward in time by setting $\chi = 1$ at the launching time and location.
Knowing χ allows to reconstruct ϕ through a path integral.

We are here interested in the (backward) source of χ.
In the backward analysis using satellite data, the source is unique at the first cloud encounter (where $\alpha = \infty$)
In the backward analysis using ERA5 detrainement, the sources are distributed along the trajectory.

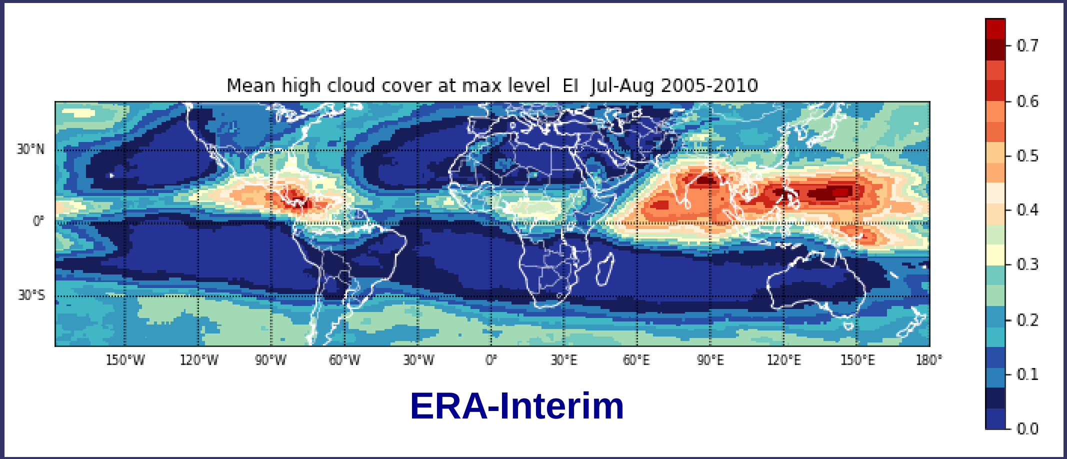
ERA5 versus ERA-Interim Cloud cover at maximum high cloud cover level

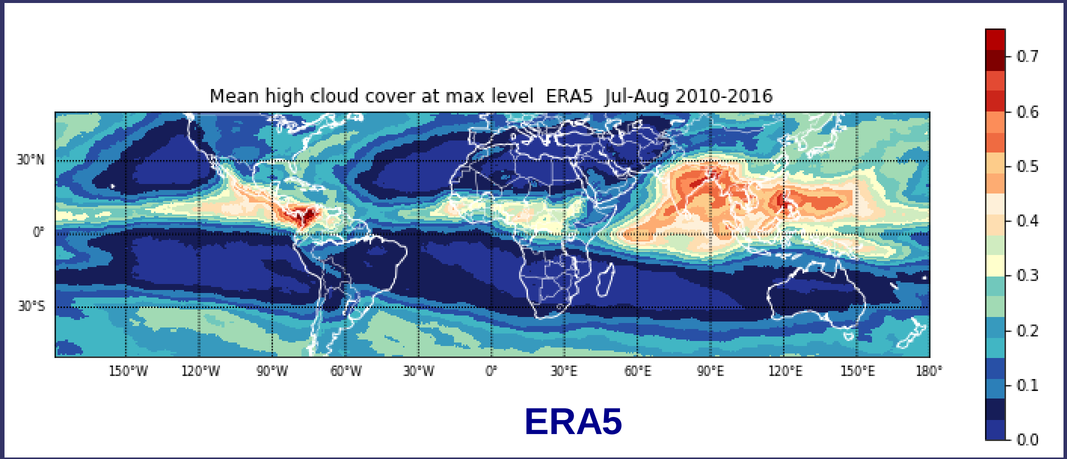
Jul-Aug

Noticeable differences between ERA-Interim and the ERA5 :

- The ERA5 is slightly warmer at the tropopause in tropical convective areas

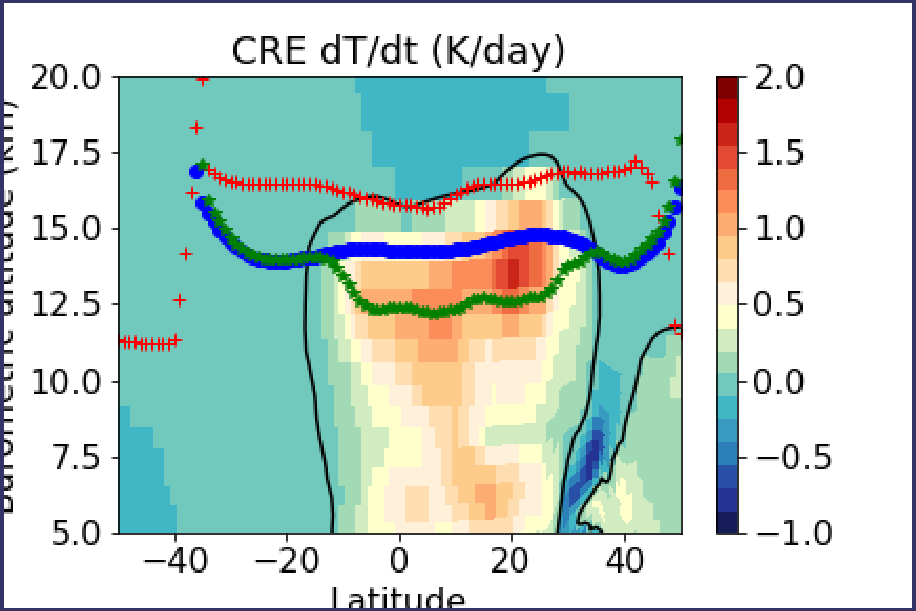
- The ERA5 cloud cover over the maritime tropics is smaller (by 30%) and culminates at lower altitude ($\Delta\theta$= -3K) than in ERA-Interim



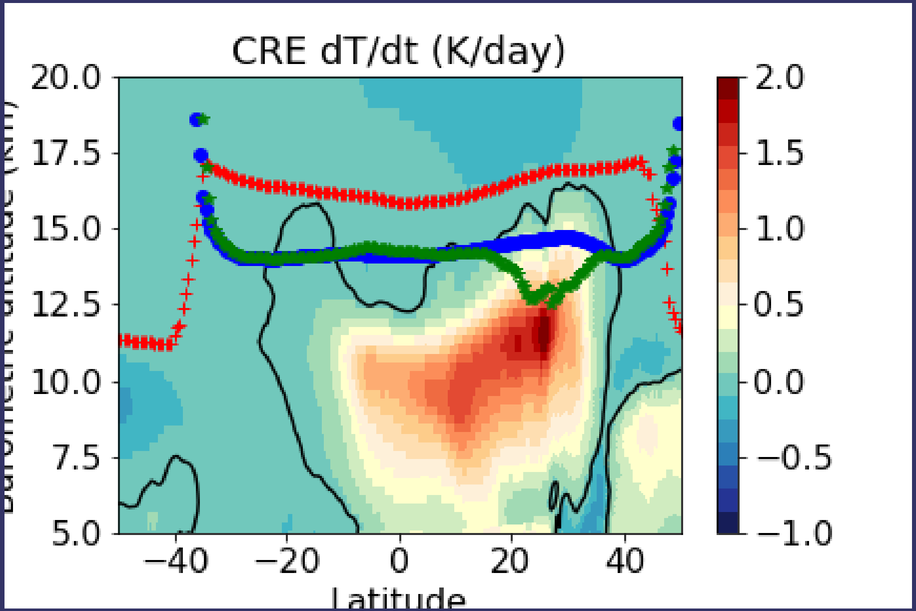


ERA5 vs ERA-Interim
Cloud radiative heating in the Asian monsoon region (Jul-Aug 2005-2010)

ERA-Interim

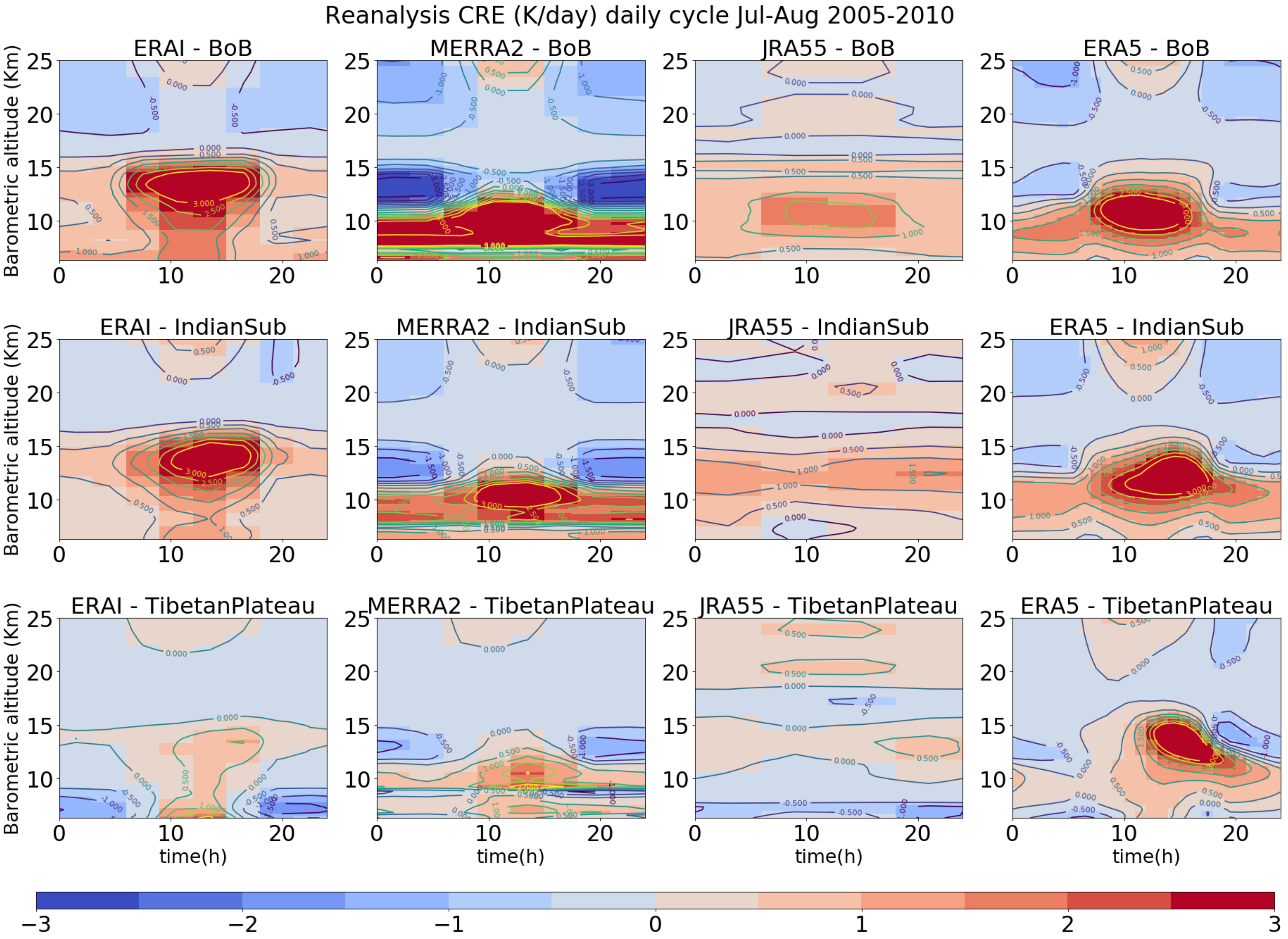


ERA5

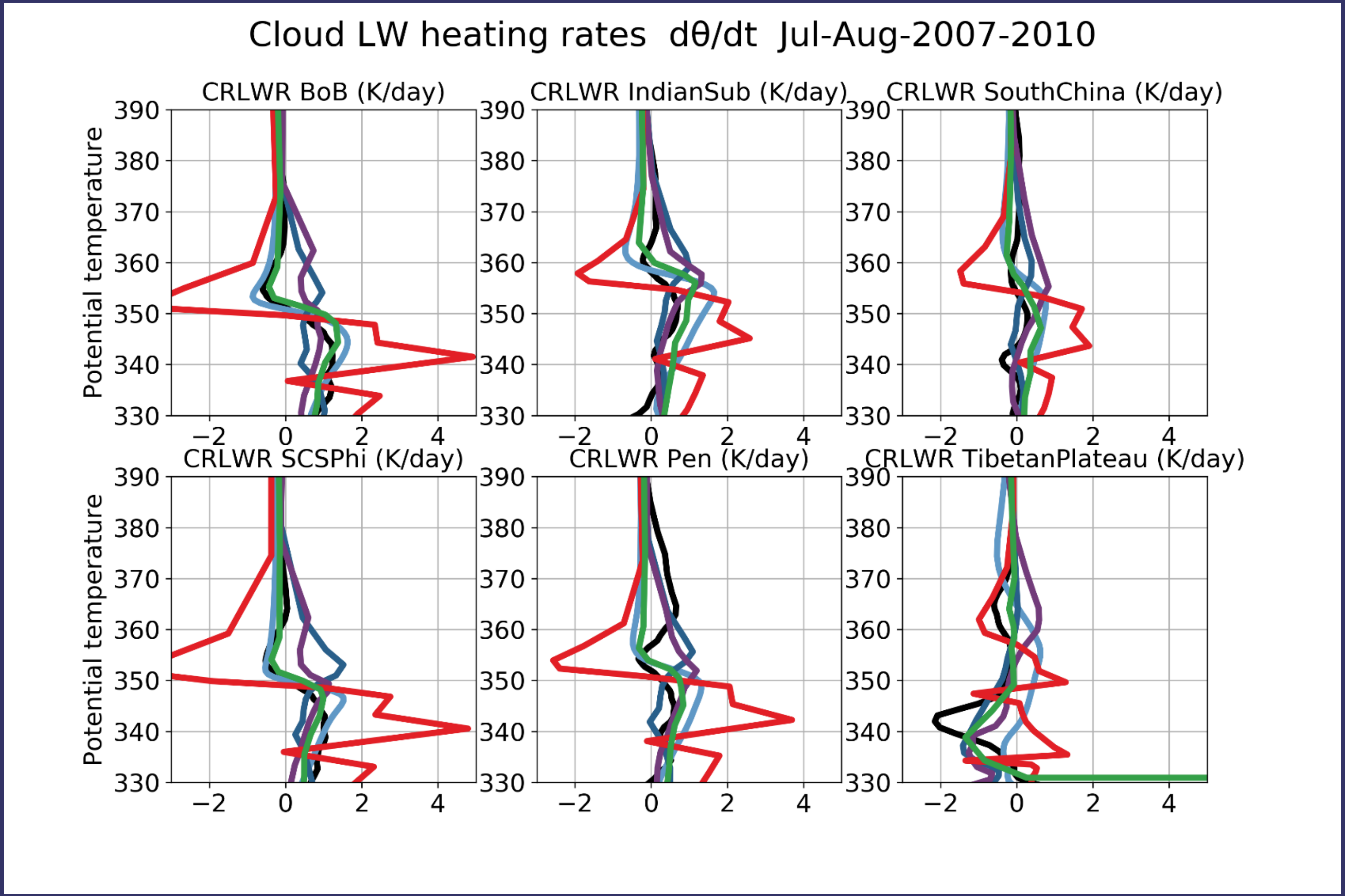


Cloud radiative effect extends higher in the ERA-Interim reaching above the clear sky LZRH, therefore its has strong and extended effect on the LZRH. CRH is confined to lower levels in ERA5 with less effect on LZRH except above continental Asia.

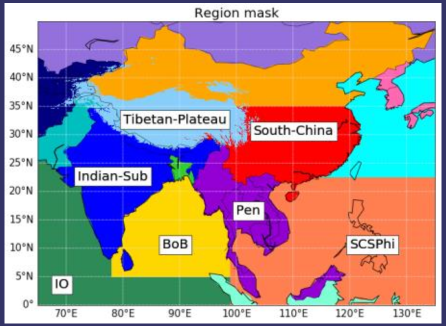
++++++ thermal tropopause
oooooo clear sky LZRH
******* all sky LZRH


Reanalysis CRE (K/day) daily cycle Jul-Aug 2005-2010
ERAI - BoB
MERRA2 - BoB
JRA55 - BoB
ERA5 - BoB
ERAI - IndianSub
MERRA2 - IndianSub
JRA55 - IndianSub
ERA5 - IndianSub
ERAI - TibetanPlateau
MERRA2 - TibetanPlateau
JRA55 - TibetanPlateau
ERA5 - TibetanPlateau
Barometric altitude (Km)
time(h)
−3
−2
−1
0
1
2
3

FLXHR
ERA5
EI
JRA55
MERRA2
CFSR



Cloud LW heating rates dθ/dt Jul-Aug-2007-2010
CRLWR BoB (K/day)
CRLWR IndianSub (K/day)
CRLWR SouthChina (K/day)
CRLWR SCSPhi (K/day)
CRLWR Pen (K/day)
CRLWR TibetanPlateau (K/day)
Potential temperature
390
380
370
360
350
340
330
−2
0
2
4

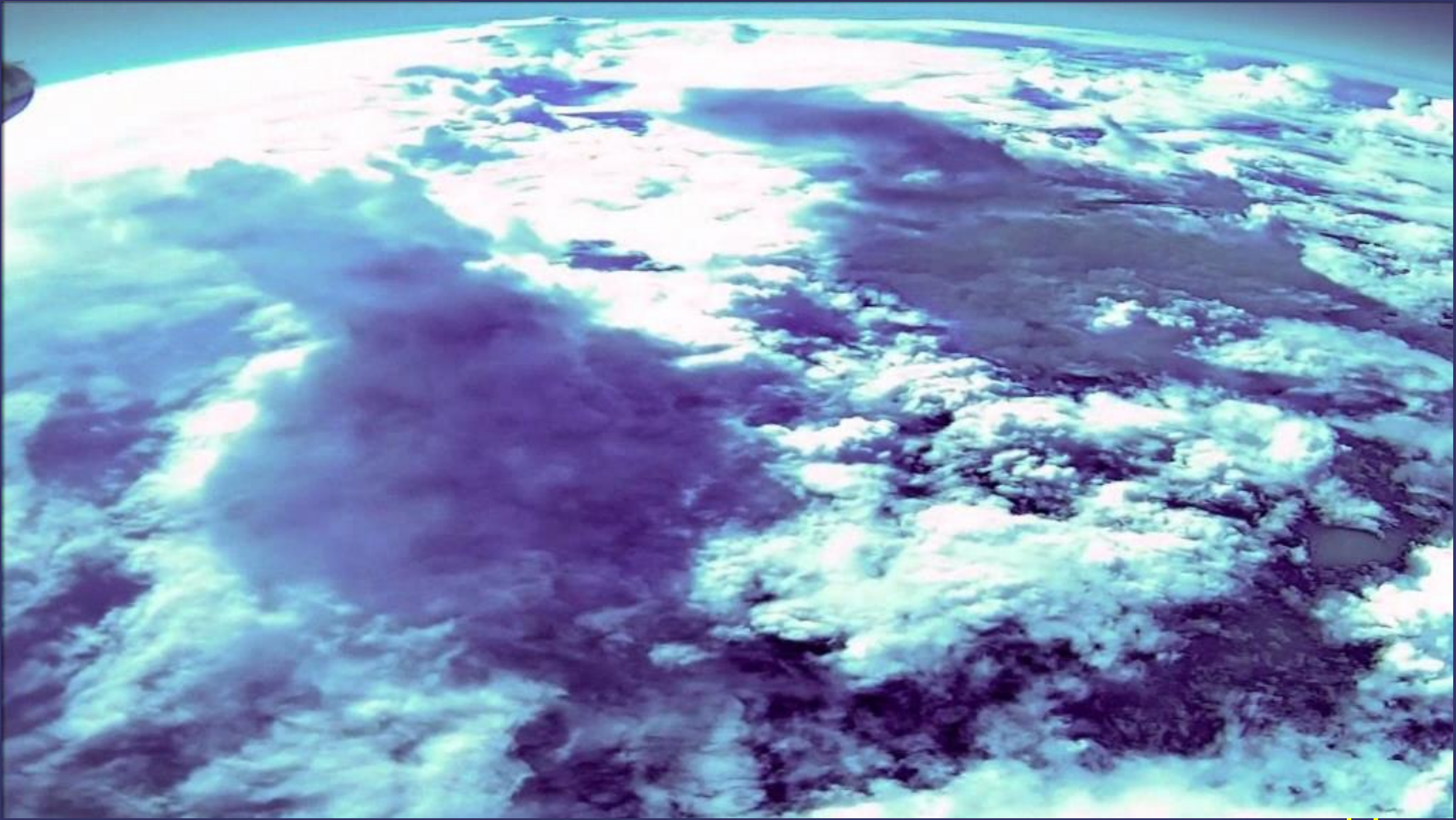


Region mask
Tibetan-Plateau
South-China
Indian-Sub
Pen
BoB
SCSPhi
IO
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
70°E
80°E
90°E
100°E
110°E
120°E
130°E

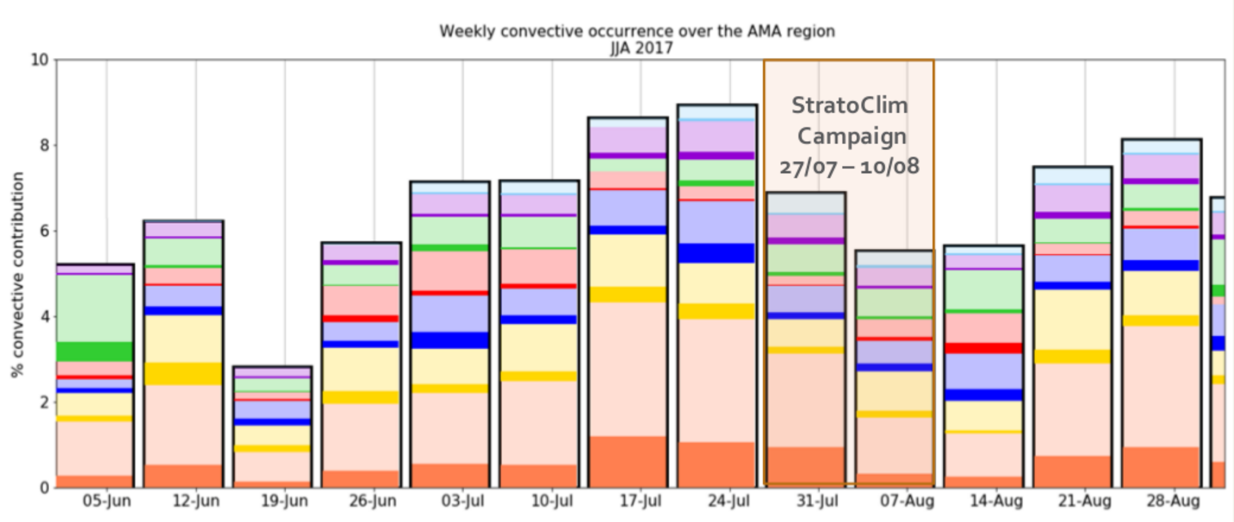
StratoClim campaign

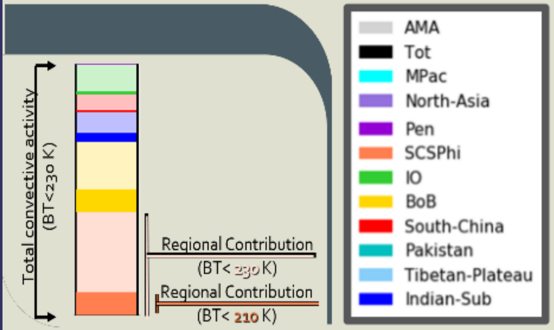
STRATOCLIM campaign 2017 from Kathmandu:
8 Geophysica M55 flights 27/07/2017 to 10/08/2017

Objectives :
- Inside and edge of the AMA
- ATAL
- Convective outflows
- Pollution impact at high altitude
- Transport and mixing within and around the AMA
- Transport pathways across the TTL
- Cirrus and the Asian monsoon
- Hydration and dehydration of the TTL
- Impact of tropical cyclones on the TTL



Convection over the AMA region during summer 2017
MSG1 – Himawari geostationary satellite observations

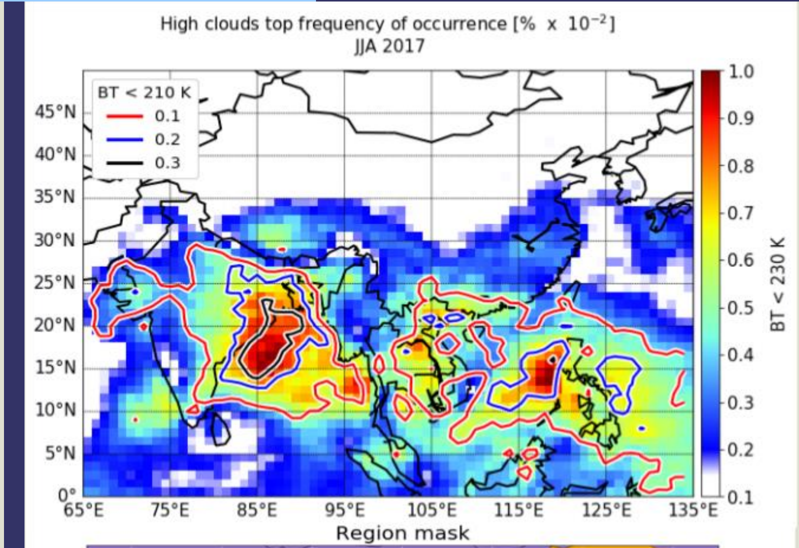


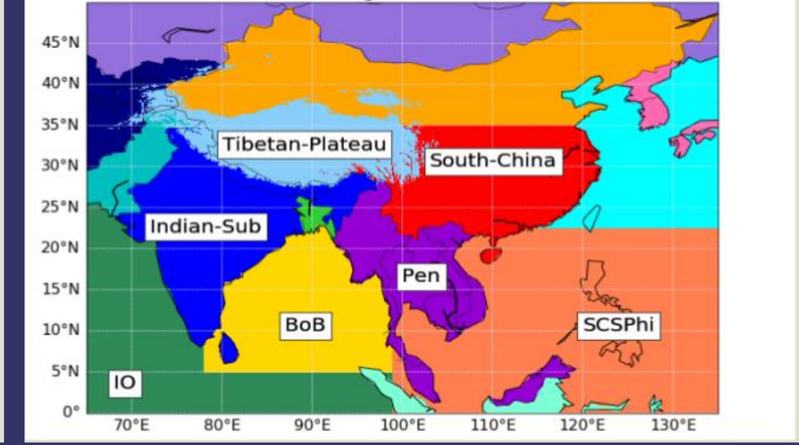


Convection over the AMA dominated by deep convection over the **Sea of China**.

Important contributions also from the **Bay of Bengal** and the Eastern Part of the **Indian Sub-continent** (potential pollution source)

StratoClim campaign taking place between 27 July and 10 August, in a period of weaker convection.

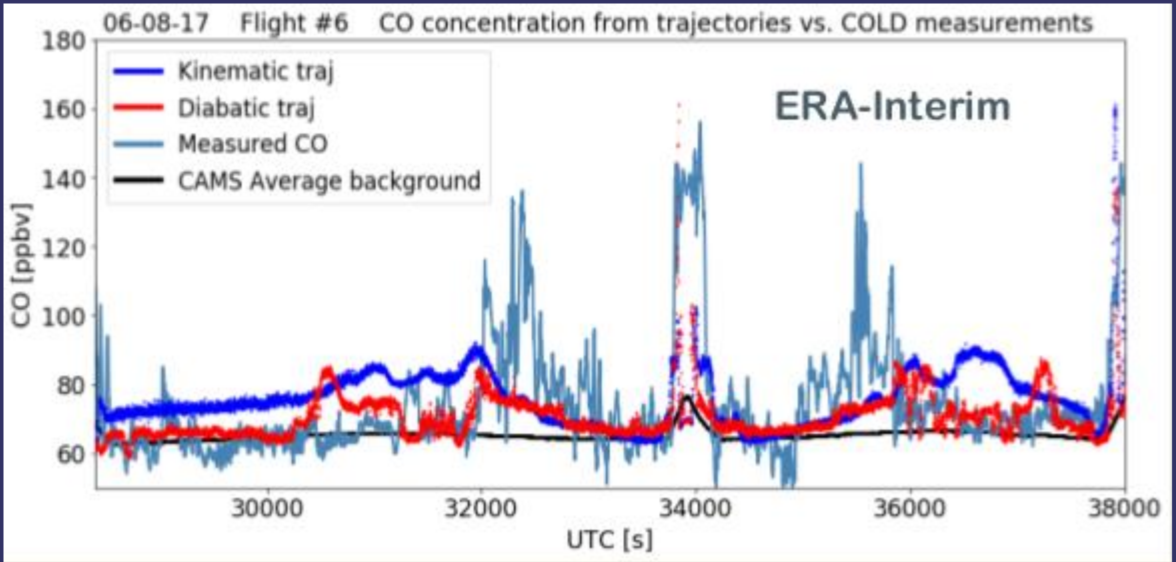


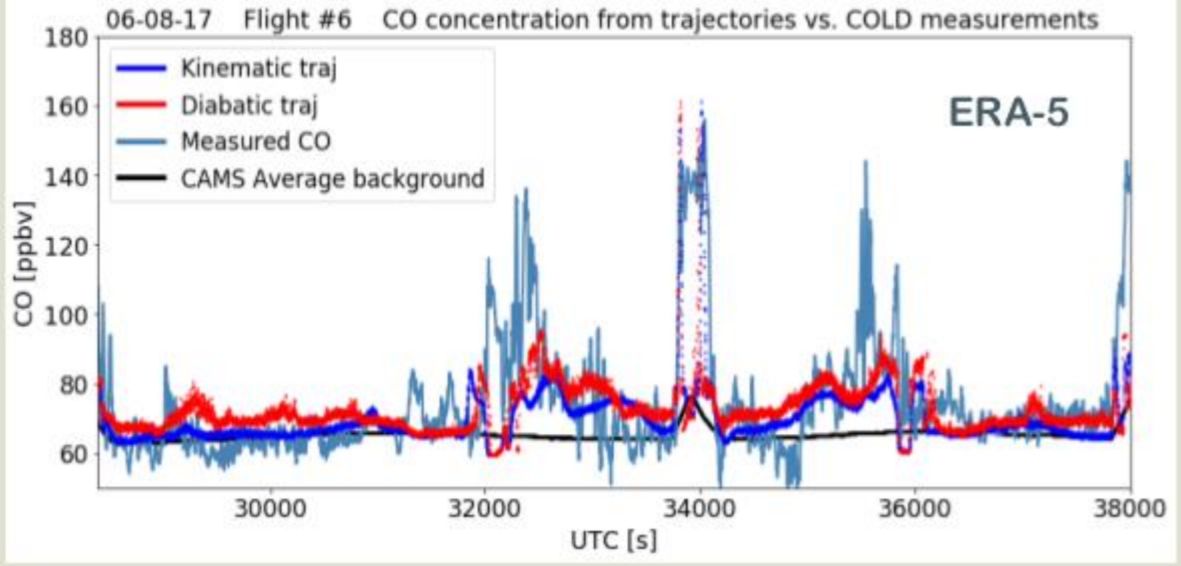


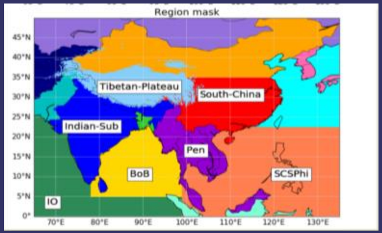
Finding the best setting : ERA5 v ERA-I and kinematic vs diabatic

Simulated values are given by adding the transported CO anomalies (trajectories + convective injections of REAS emission) to the CAMS seasonal background.

ERA-Interim misses the correct timing and extent of the plume transport, with large differences between kinematic and diabatic approaches. ERA5 better reproduces the obsrved CO with very small differences between the kinematic and diabatic settings.

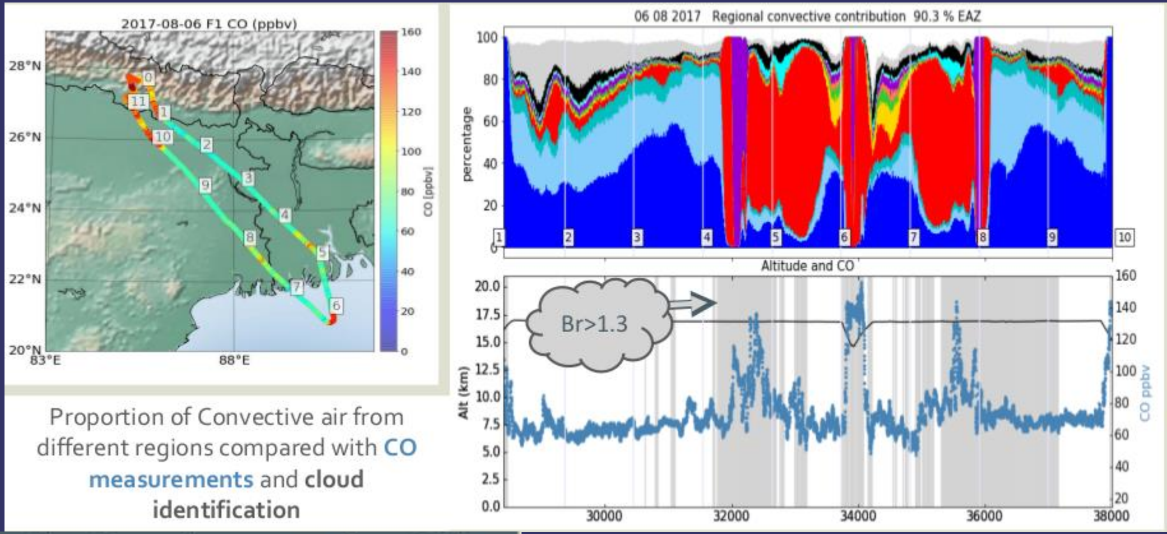




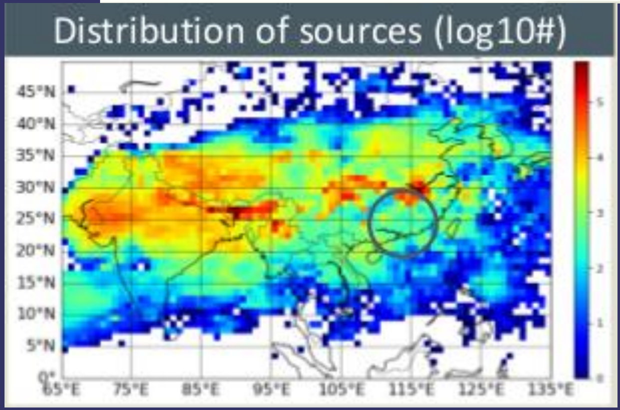


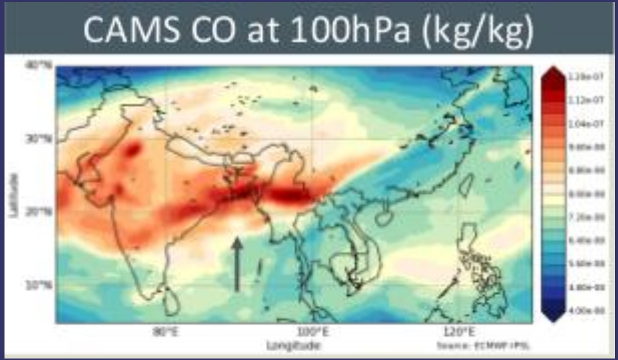
Chinese pollution plume (flight #6 06/08/2017)

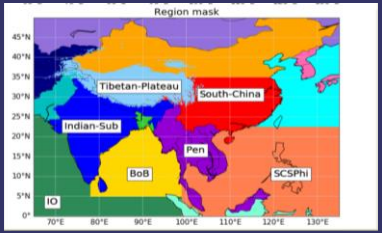
Convective injection of fresh polluted air (age ~ 2 days) over China up to 17 km (~100 hPa, possible overshoot) with CO up tp 140 ppbv . Pollution plume also seen in aerosols. Remaining part of the flight: mixing of clean and older air (10-15 days) from Insian Subcontinent and Tibetan plateau.



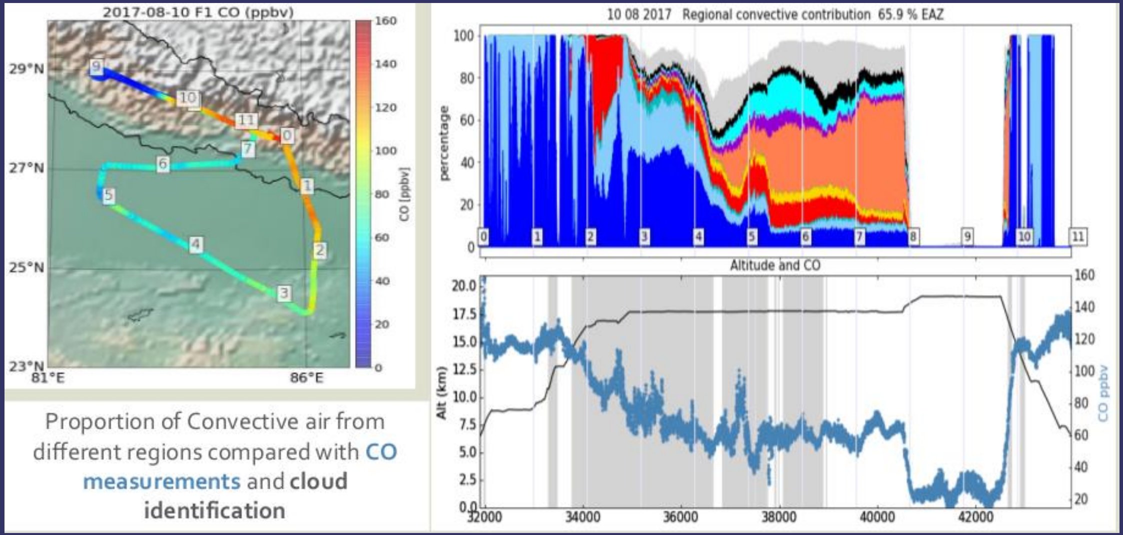
Proportion of Convective air from different regions compared with CO measurements and cloud identification







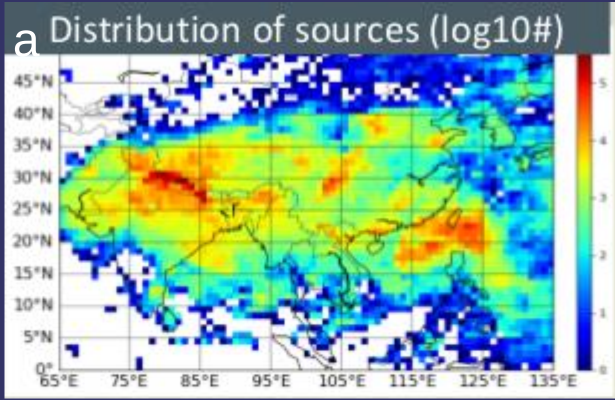
Thyphoon plume (flight #10 10/08/2017)

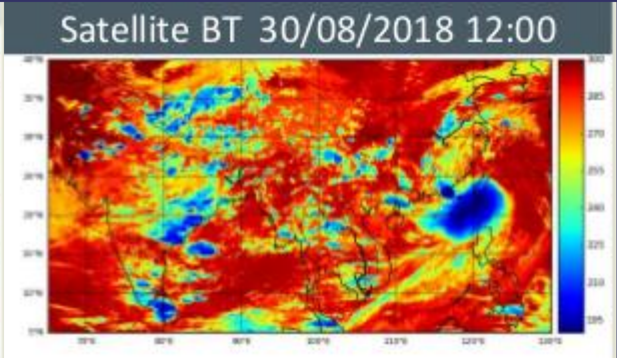


Proportion of Convective air from different regions compared with CO measurements and cloud identification

First part of the flight dominated by local convection and young parcels.

From 4 to 8 points, the flight is dominated by increasingly older and cleaner air. Those air parcels were injected in the TTL 10 days before frrm the Sea of China by a large typhoon during the last week of July.





Pathways using forward trajectories

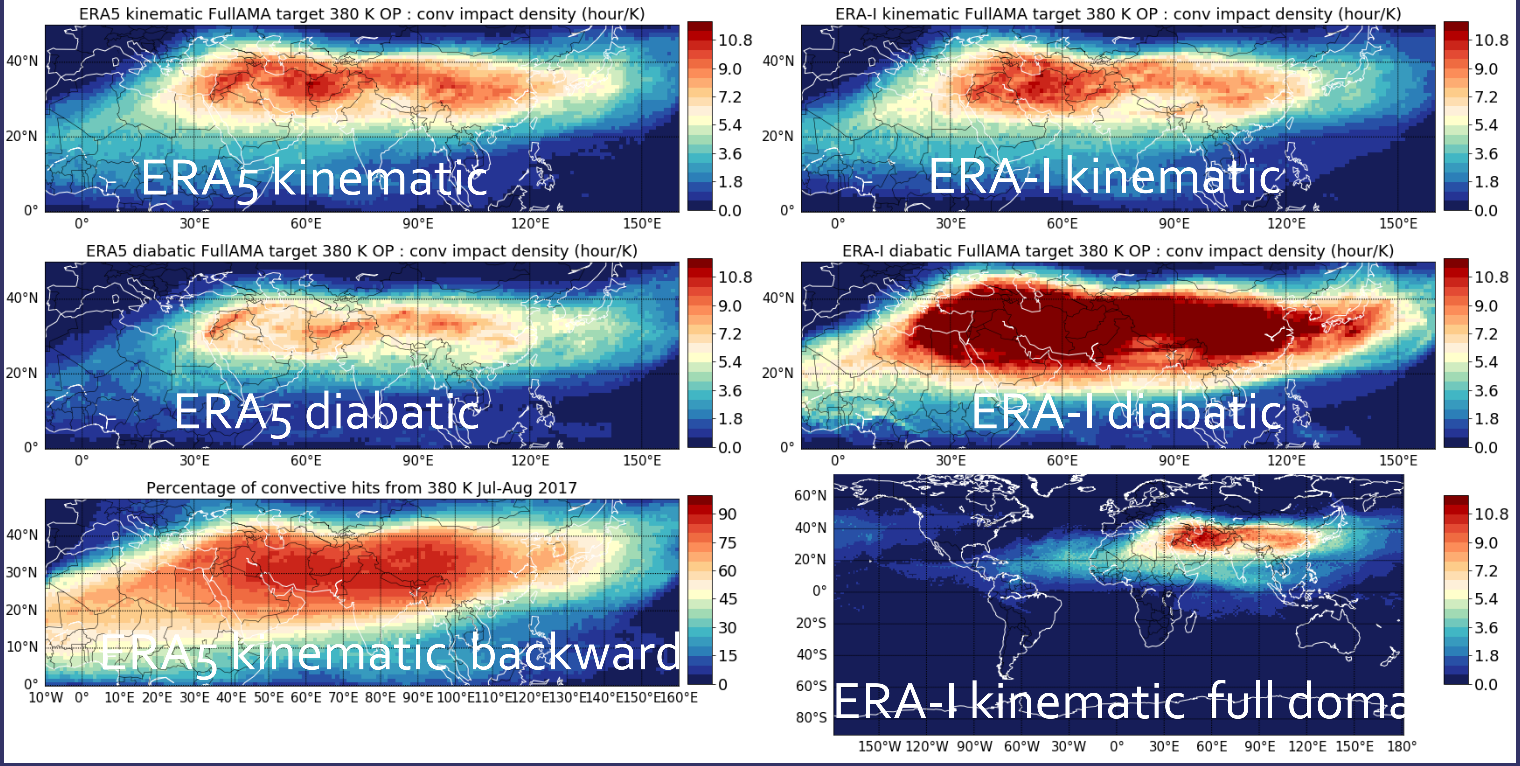
Forward trajectories launched at cloud top determined by SAFNWC with resolution 0.1°x0.1° in the AMA domain every hour for cloud tops at $p \leq 175$ hPa between 1 July and 31 August 2017. About 2 billions 44-day trajectories.

Convective impact density at θ = 380 K

Measures the # of particles that reach the level. Normalized as a density in x,y,z,θ and to be independent of the satellite pixel size and sampling rate. Exiting parcels are discarded.

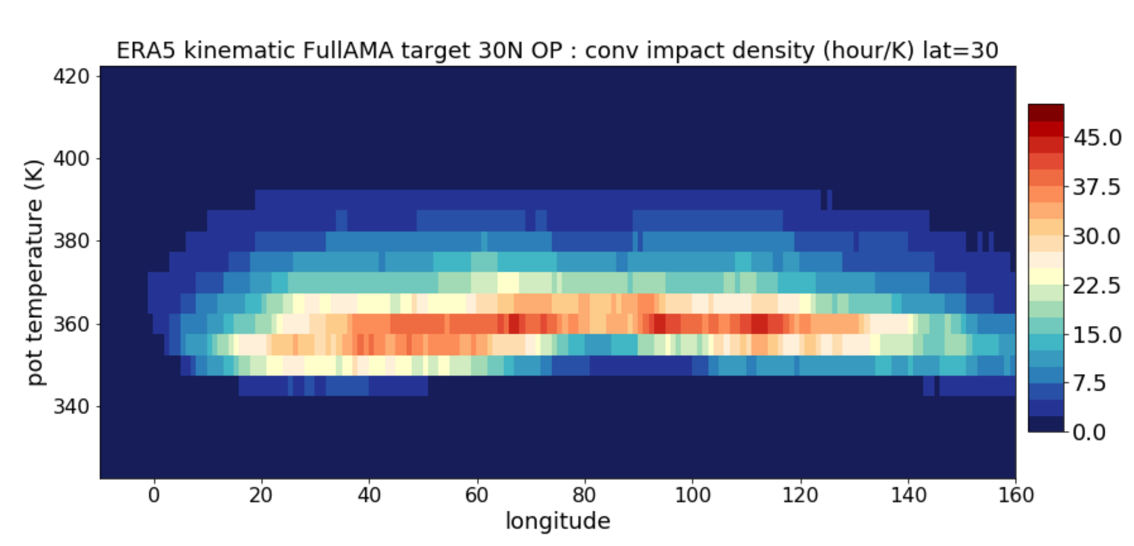
Salient points :

- Very good agreement ERA5 and ERA-I kinematic
- Excessive vertical transport in ERA-I diabatic (x2)
- Confinement of parcels in both the AMA and global domain
- Agreement with backward proba of convective hits from 380K



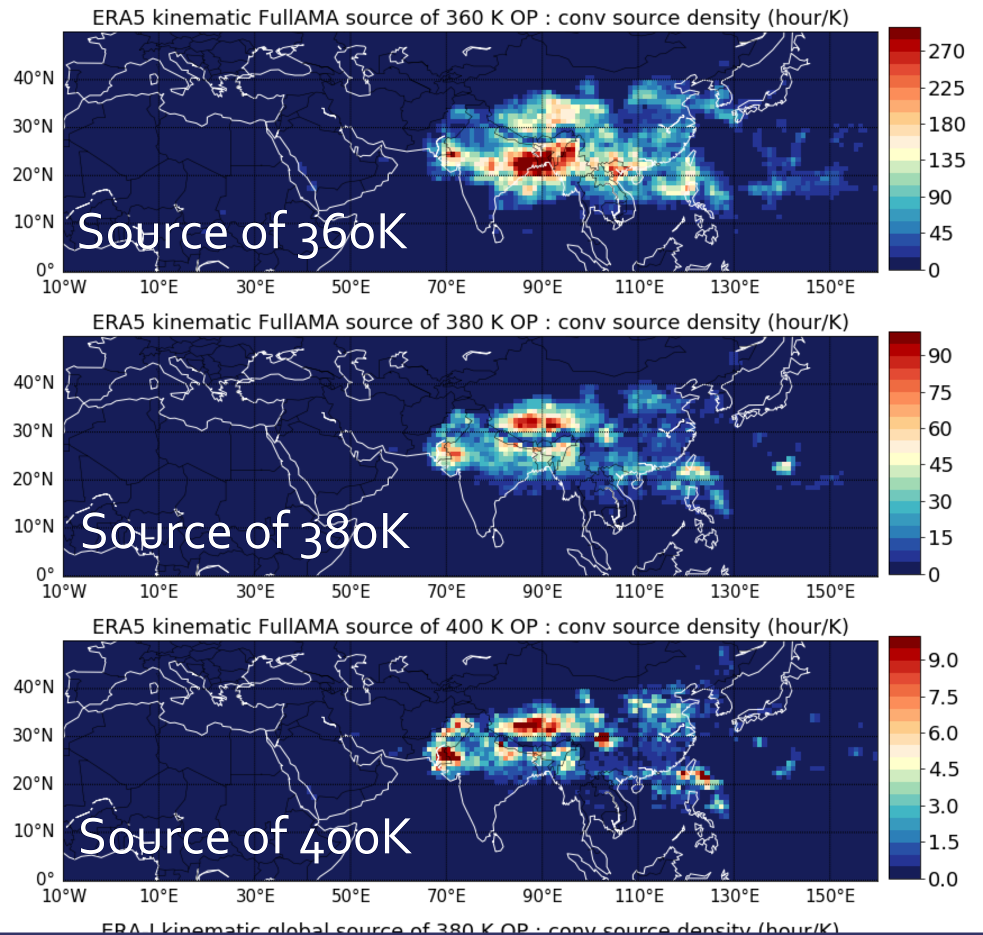
Confinement layer (ATAL)

Confinement begins above 340K and is maximum at 360K, which is also the altitude of teh AMA westerly and easterly jets. It extends up to 400 K



The 350K layer is depleted in confined parcels above the most convcetive regions due to the divergence of the convcetive upward flux and concentatrate parcels in adjacent regions of descending motion.

Source distribution



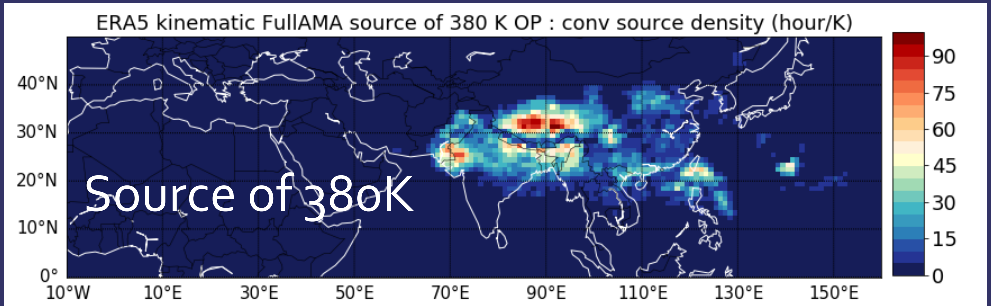
At 360K, the major sources are at the north of the Bay of Bengal.

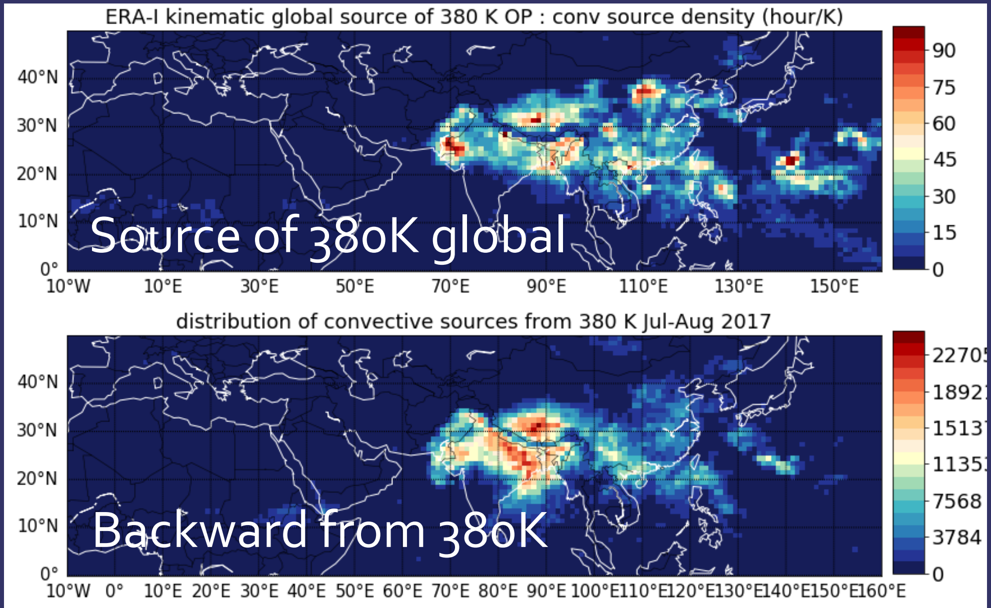
At 380K and 400K, the sources of confined parcels concentrate aver the Asian continent (North India, China, Pakistan and the Tibetan Plateau).

The Himalayan slope is NOT a source region.

Source distribution (contd)

The sources for the global 380 K layer are much more distributed with a larger (X3) maritime component.

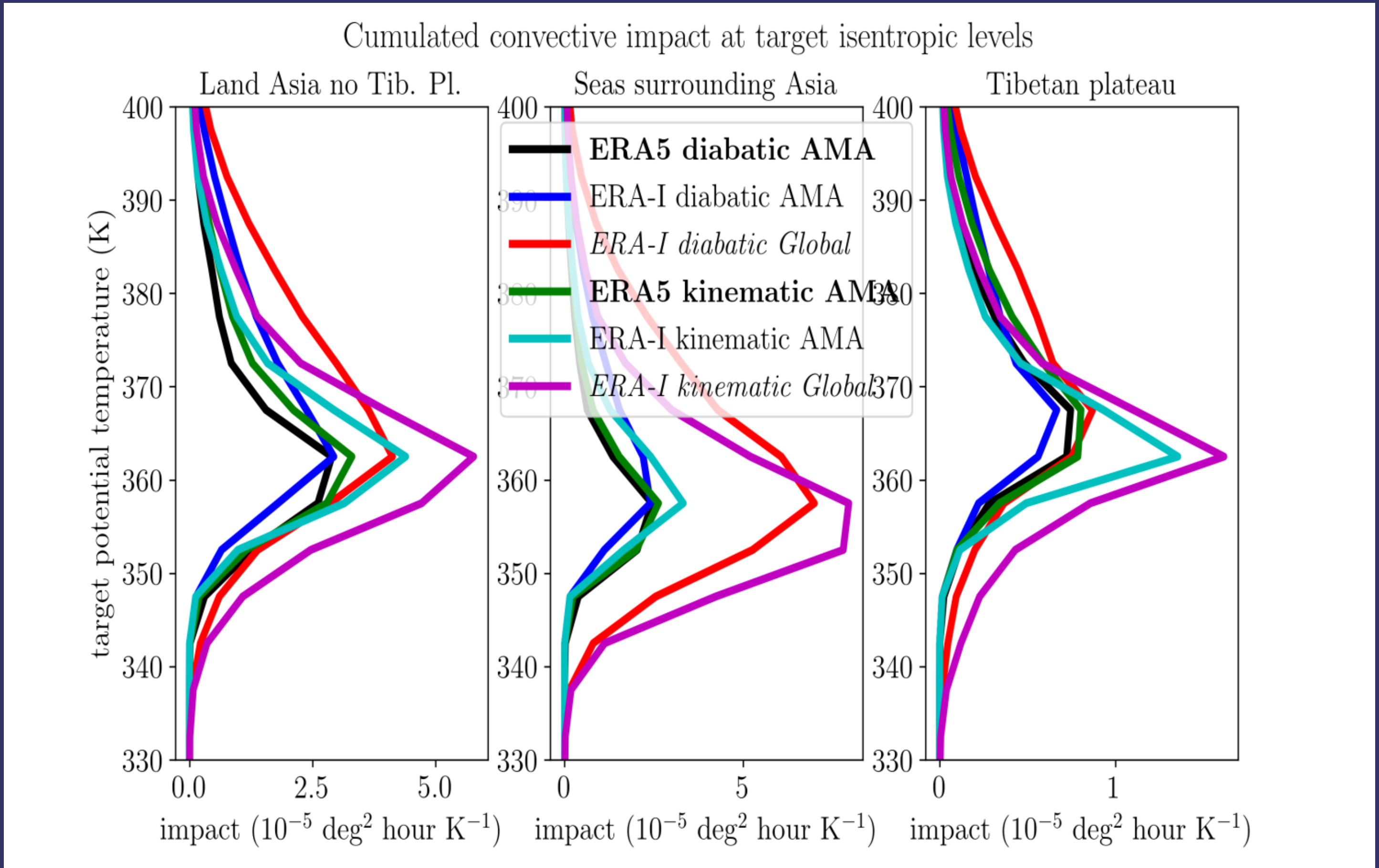




The sources from backward trajectories initiated on the 380K surface are in agreement with the forward calculations.

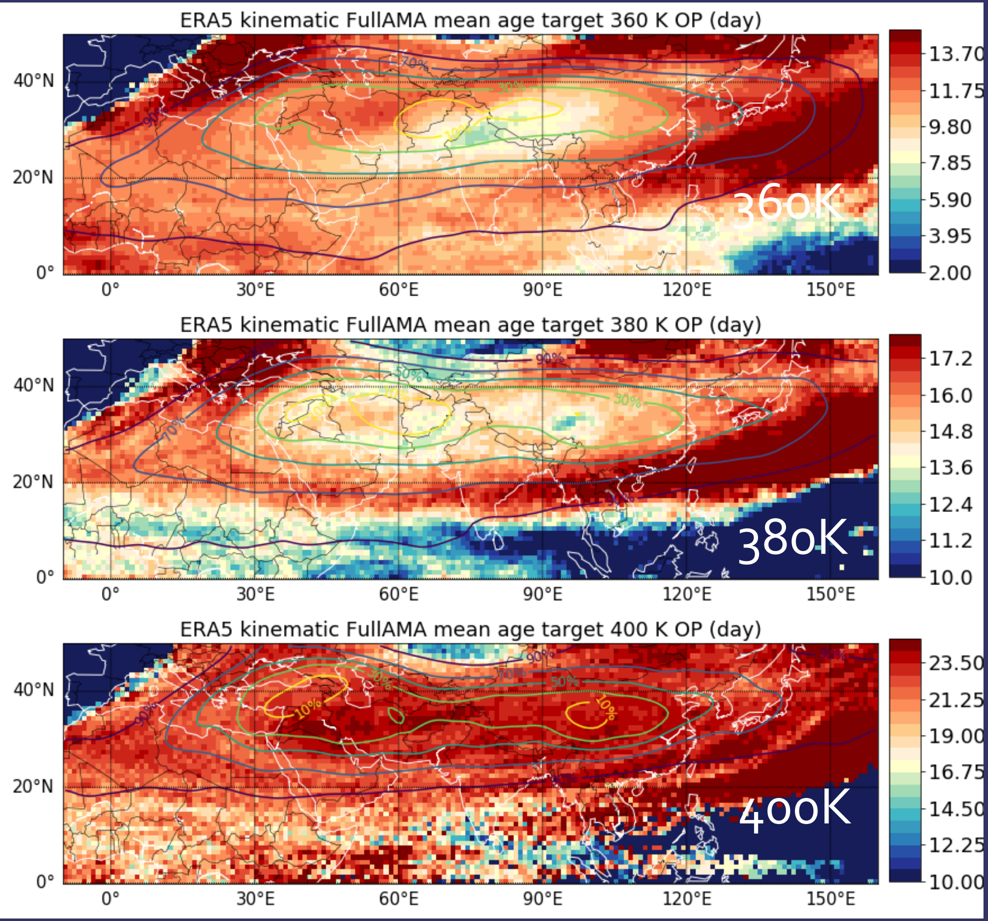
Cumulated impact per source region as a function of the impact barometric altitude

- The level of maximum confinement is the same for all diab/kin ERA-I / ERA5.
- The impact of the oceanic regions is multiplied per 3 in the global domain / AMA domain.
- The overall Tibetan plateau contribution is 13 % in the AMA domain and 9 % in the global domain.



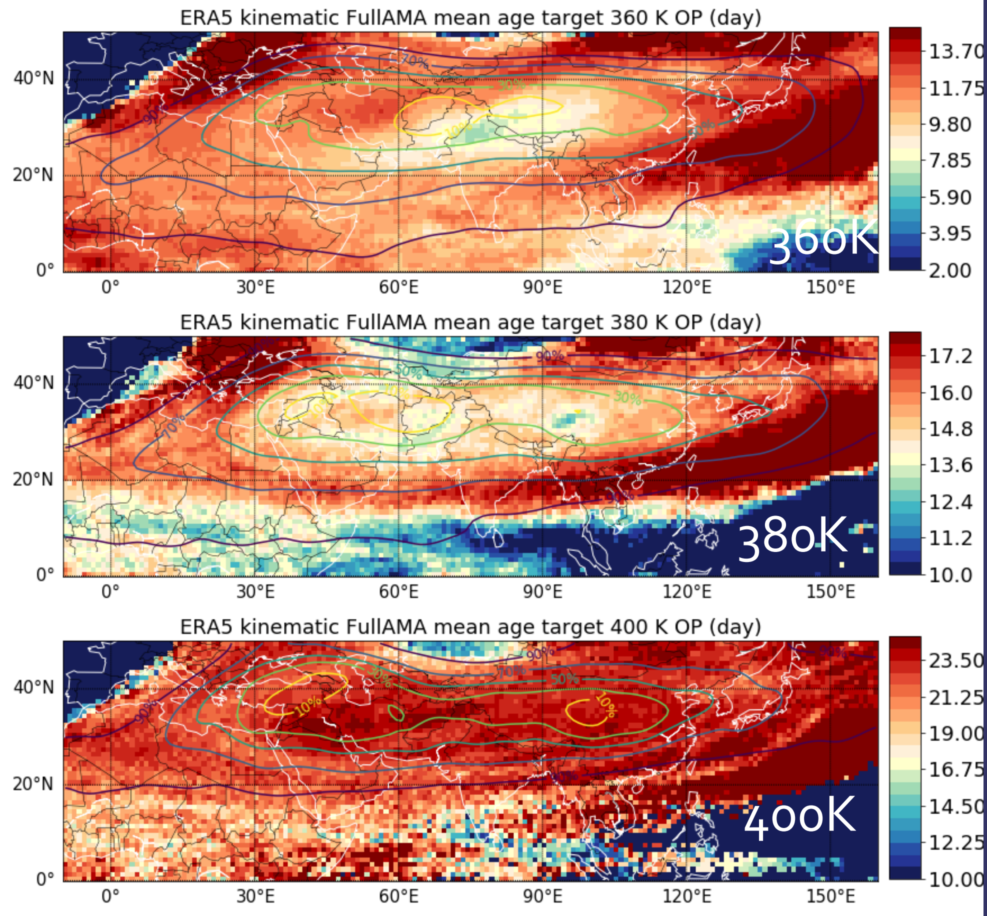
Age of air / convection

Mean age + contours of the proportion of cumulated impact

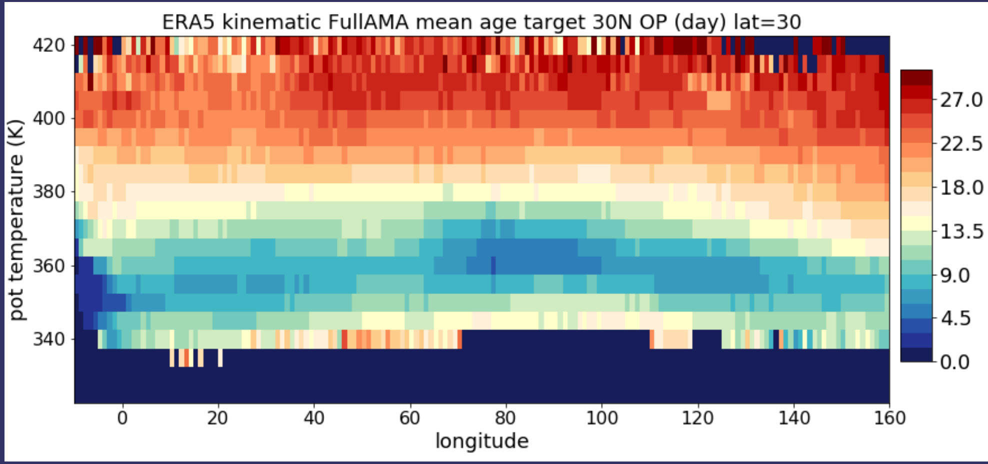


At 360K and 380K, no trapping within the core of the AMA where the age exhibits a relative minimum, as parcels are constantly renewed by fresh injection of young air. Older air circulates at the periphery of the AMA. Some trapping within the core is observed at 400K, in a layer hardly reached directly by convection.

Age of air / convection



The dome of young air in the core of AMA is visible in the longitudinal section at 30N

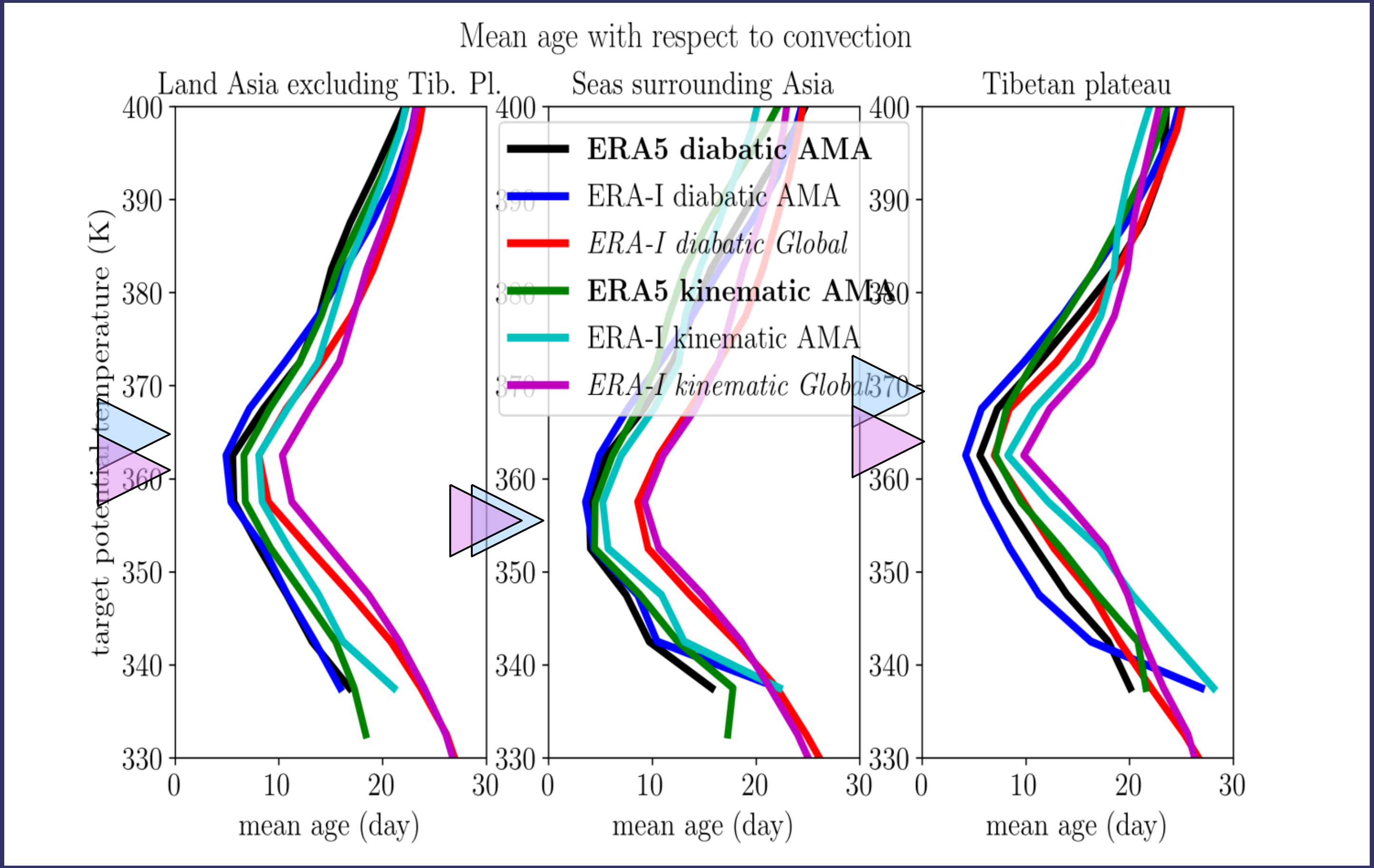


Mean age per region as a function of the impact potential temperature

Minimum mean age near the all-sky level of zero radiative heating for both diabatic and kinematic (!) trajectories.

Age from oceanic region < age from Asia land < age from Tibet

Consistent with more confinement of air from continental convection.



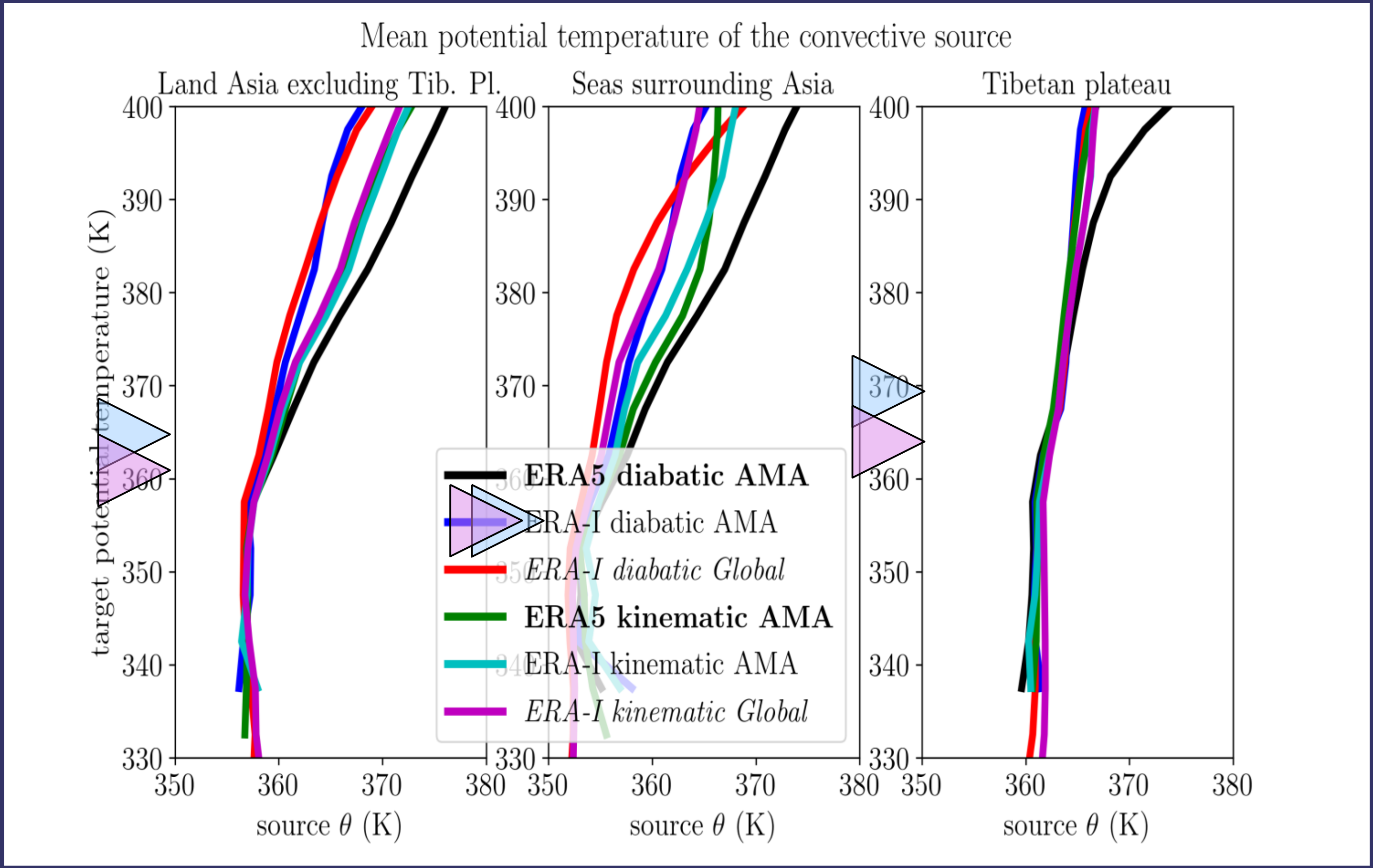
Clear & All sky ERA5 LZRH

Mean vertical source potential temperature per region as a function of the impact potential temperature

Uniform value up to the LZRH. Decending parcels from belo the LZRH

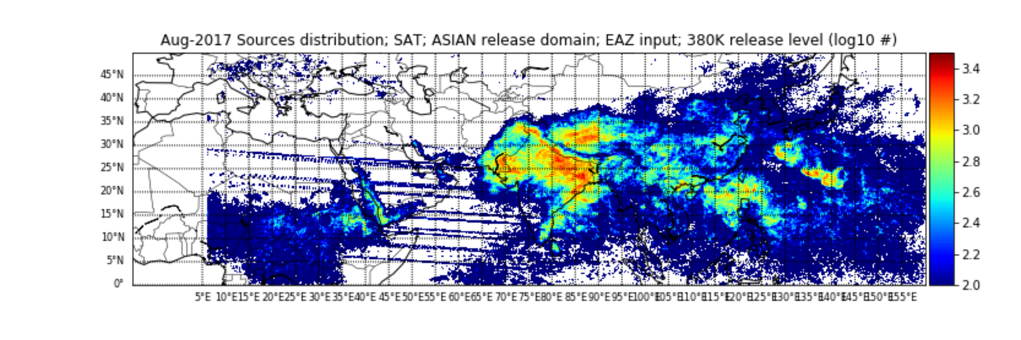
Growth above the LZRH due to detrainment by high clouds, with largest slope for ERA5 diabatic.

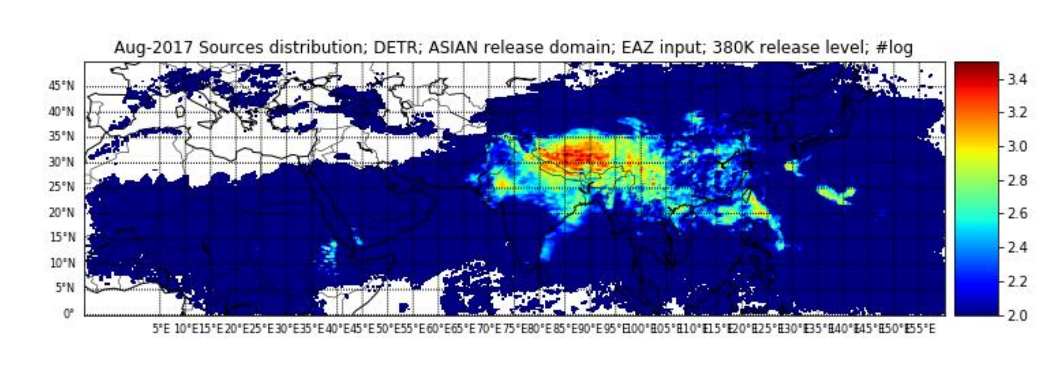
Most of the parcel reaching the LZRH originate from above the all sky LZRH.



Limitation : sensitivity to the cloud top distribution

Brightness temperature method versus ERA5 detrainment method





The ERA5 exhibits high penetrative convection over the Tibetan plateau which dominates the sources when detrainment properties from the model are used to anlyse

Summary and discussion

Confinement of convective parcels in the Asian Monsoon Anticyclone up to 400K. The main sources of the AMA are in continental regions in Northen India, China and the Tibetan Plateau.

Age of air minimal in the AMA core due to renewal by fresh convection injecting above the LZRH.

However, the largest flux at the global 380K surface comes from the maritime regions surrounding Asia, especially from the Sea of China. This air does not penetrates the AMA core but circulates on its southern and western flank where it is injected into the stratosphere.

Both diabatic and kinematic trajectories generate confinement and the vertical transit properties such as distribution of sources end age are robust. However, ERA-Interim diabatic transport is much too strong due to excessive cloud radiative forcing.

Main feeders of the TTL are the clouds that reach above the all-sky LZRH with contrbiutions up to the cold tropopause. These cluds are rare and our results are sensitive to the retrieval of their properties from satellite observations and their representations in model. Largest discrepancies between satellite and model bsed mathods are observed over the Tibetan Plateau.