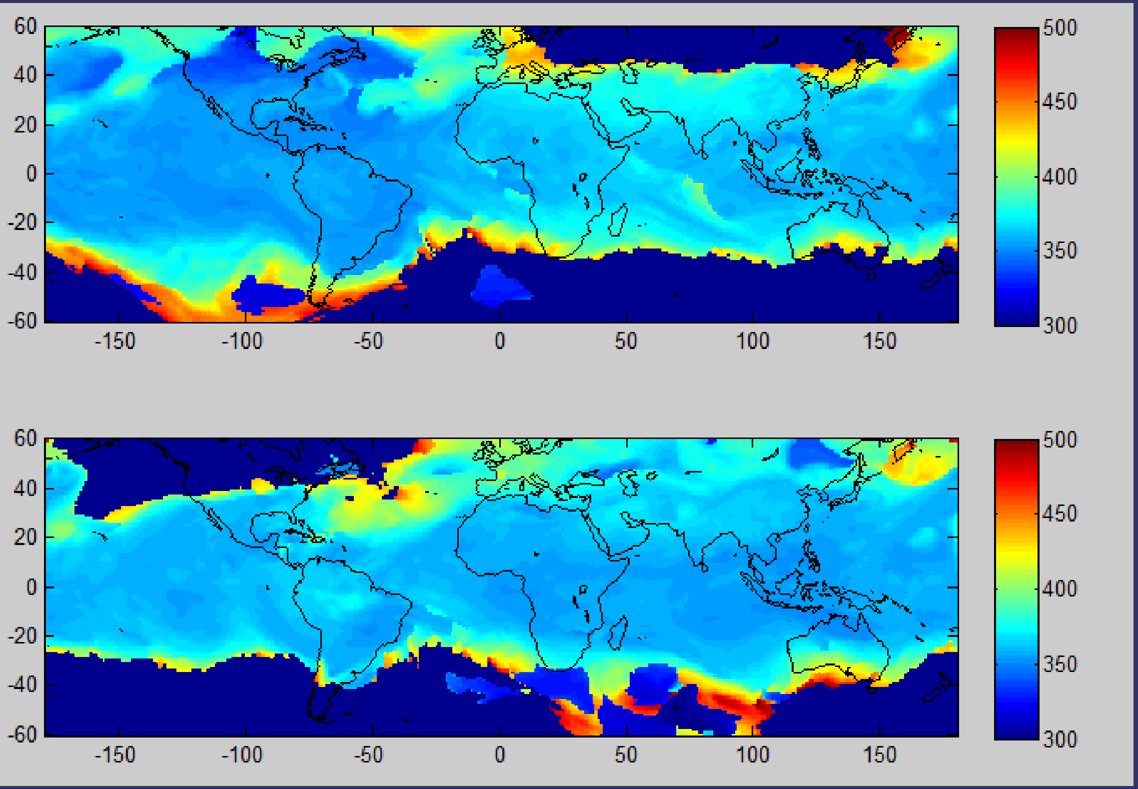
Transport in the TTL and convective sources



Bernard Legras[1], Ann'Sophie Tissier[1], Alexandra Tzella[1,2]

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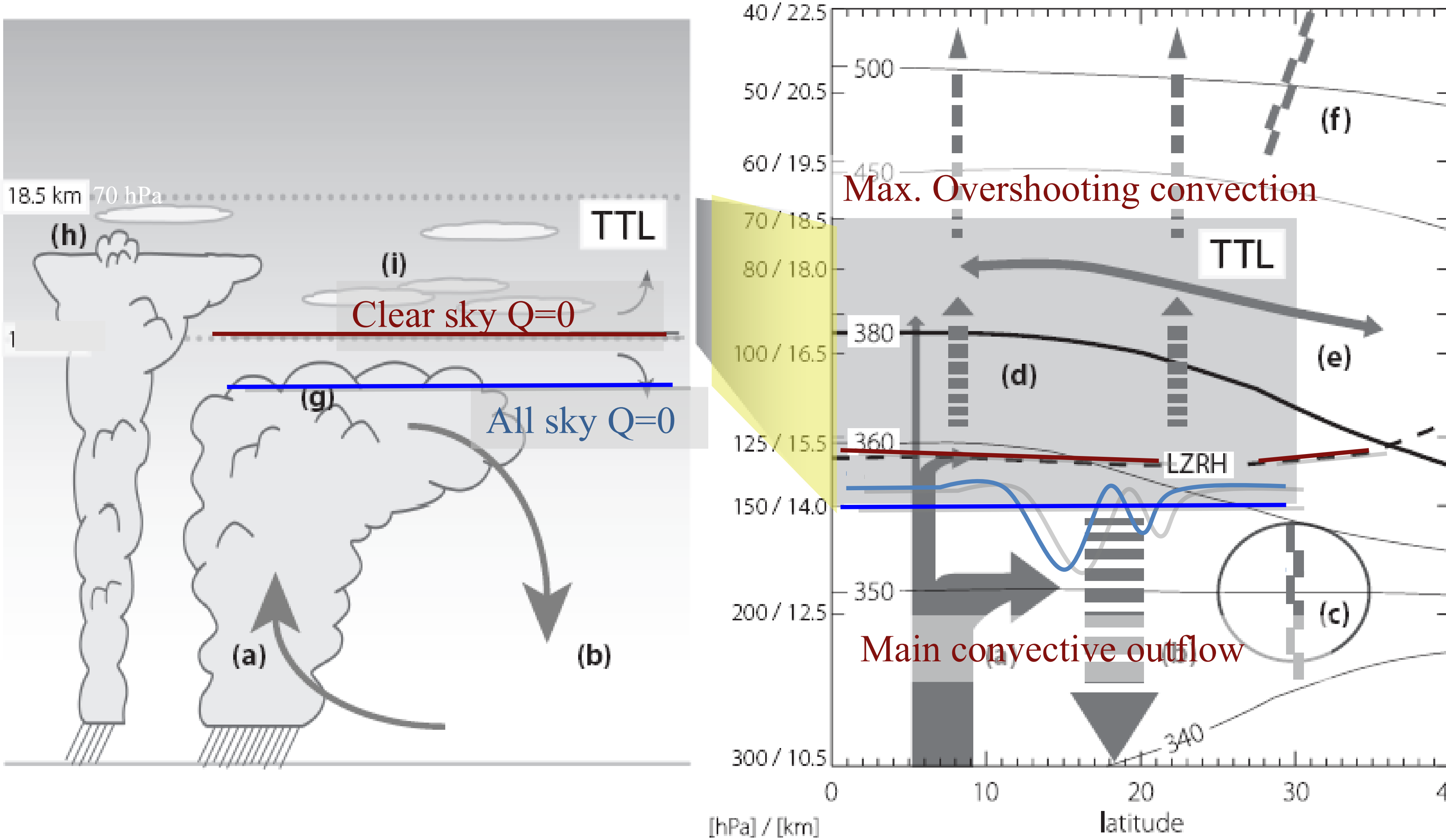
2: University of Birmingham, UK

See also poster by A.S. Tissier

16 January 2014, SPARC Vth GA, Queenstown, NZ

The Tropical Tropopause Layer

The Tropical Tropopause Layer (TTL) is an intermediate region between the convection-dominated troposphere and the radiation-dominated stratosphere.
Gate for all the compounds entering the stratosphere.

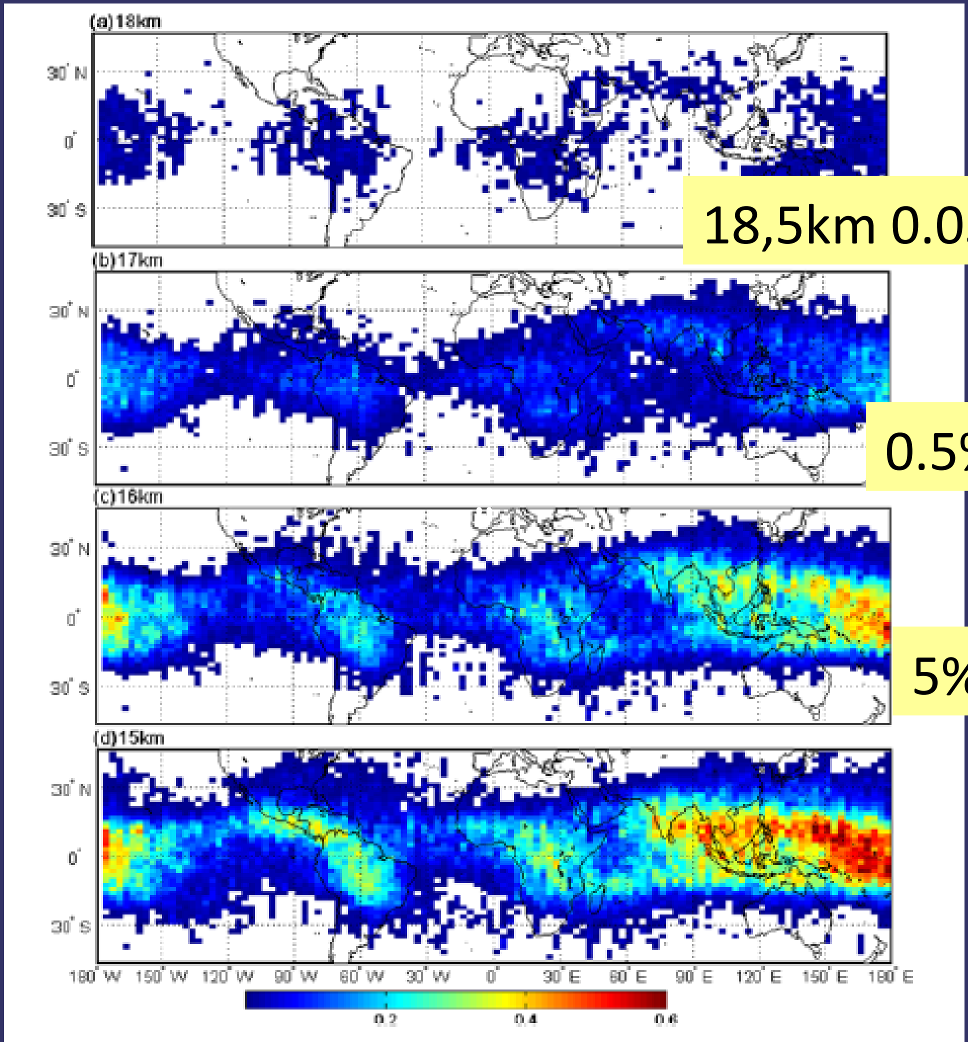


Adapted from Fueglistaler et al. (Rev. Geophys., 2008)

Convection hardly reaches the tropopause. Most clouds detrain below 15 km. Only a very small fraction (<0,5% in all seasons) is reaching the tropopause.

Liu and Zipser, JGR, 2005
Rosslow and Pearl, GRL, 2007
Fu et al, GRL, 2007
Yang et al., JGR, 2010

Cloud fraction according to CALIOP



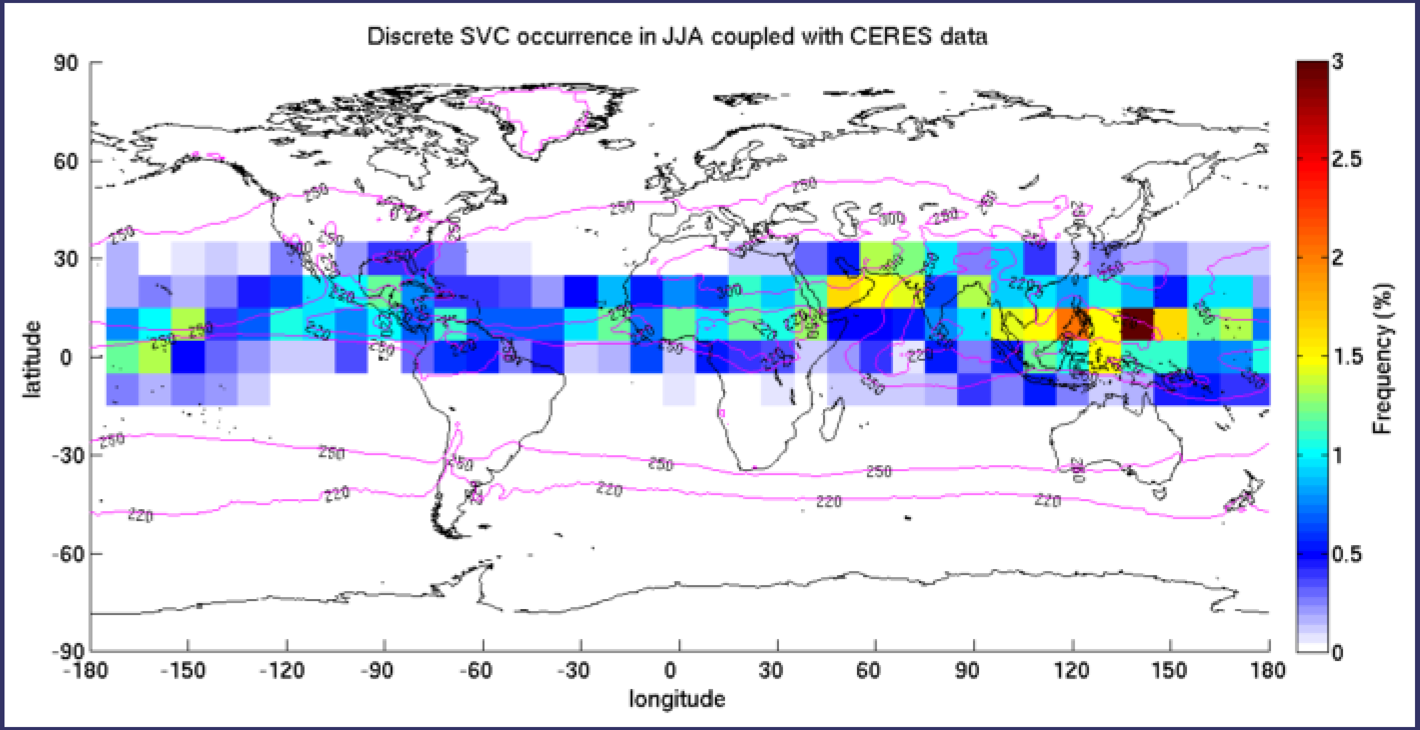
18,5km 0.05%

0.5%

5%

Fu et al, 2007

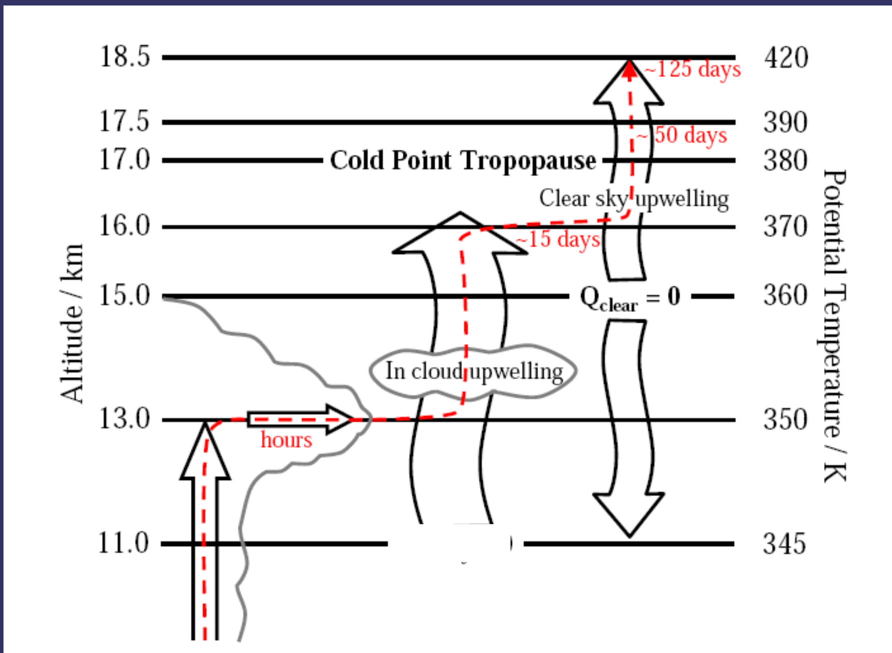
Subvisible cirrus clouds (T<-40°C, optical depth < 0.03)
Average from CALIOP
June-July-August 2006-2008

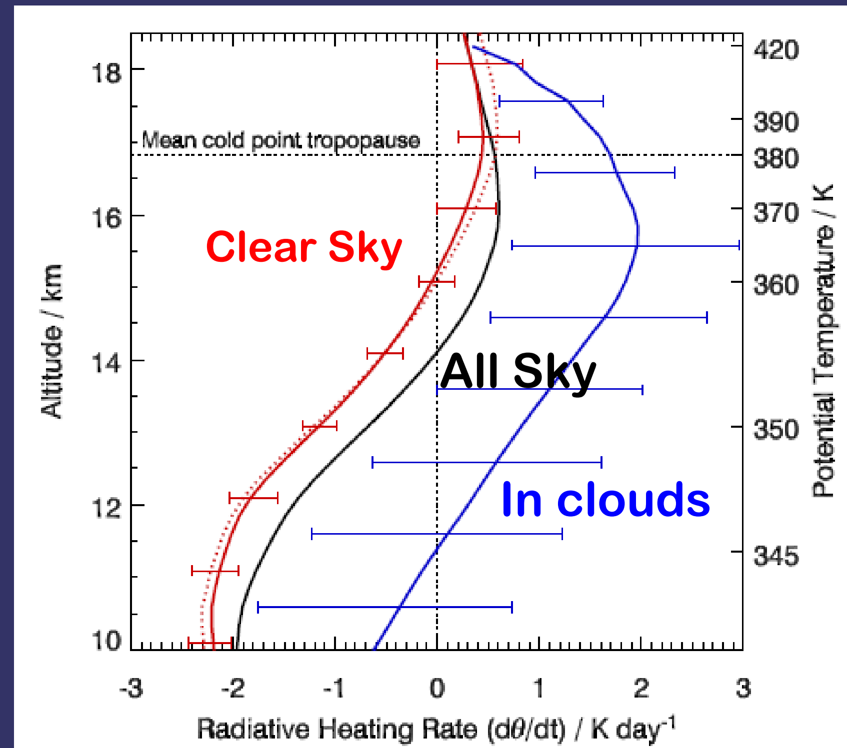


Thin cirrus extend over a large range in the tropics above convective regions and downstream of the Asian monsoon.
Martins et al., JGR, 2011
Reverdy et al., ACP, 2012

Heating rates in the TTL

Crossing of the LZRH



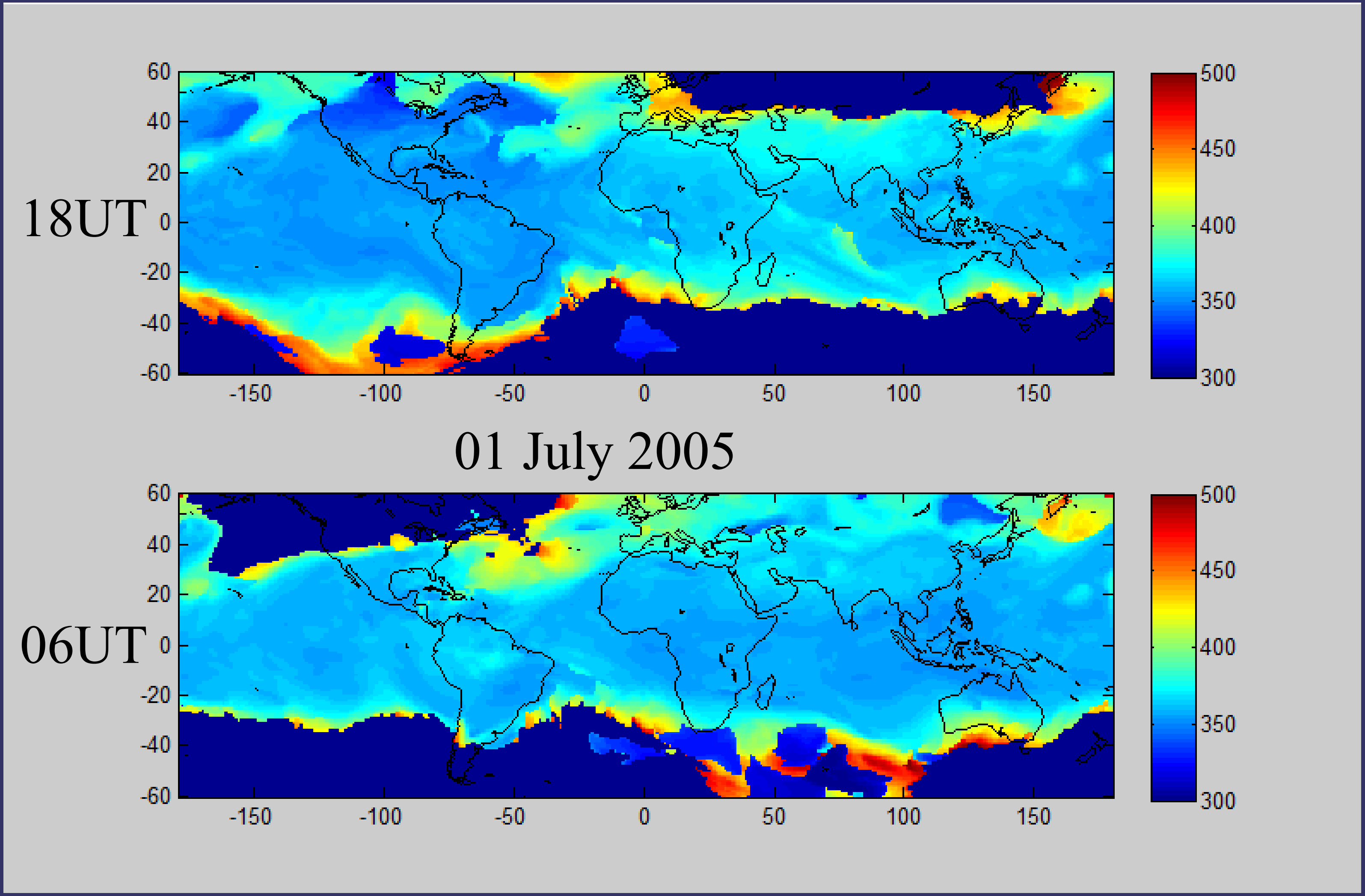


Clear sky LZRH : 360K
All sky LZRH : 355K

Corti et al., ACP, 2005
James et al., GRL, 2008

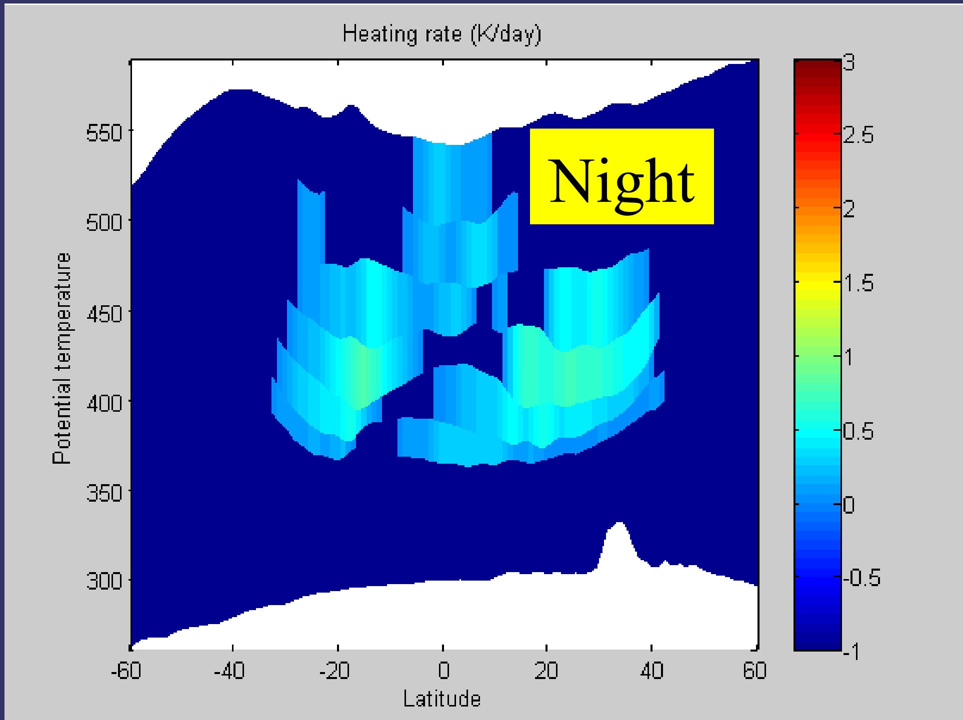
Most of the convection detrains below the all sky LZRH.
Cloud radiative heating lowers the LZRH but is highly intermittent

Potential temperature of the clear sky LZRH (ERA_Interim data)

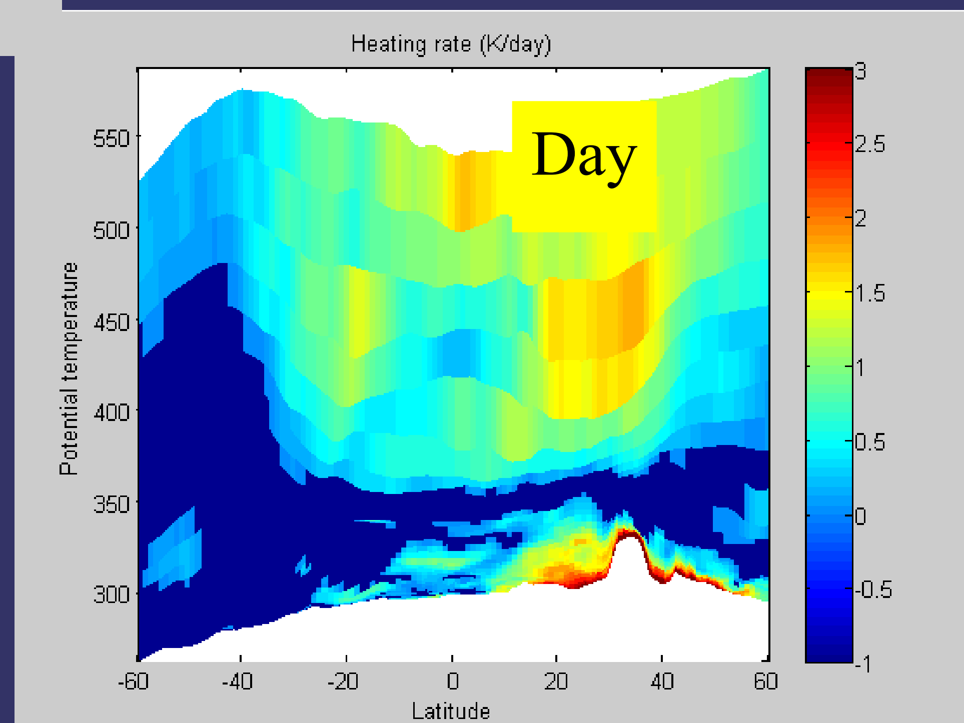


Distribution of 3-hourly clear sky heating rate

Meridional sections



01 July 2005, 06UT, 80E

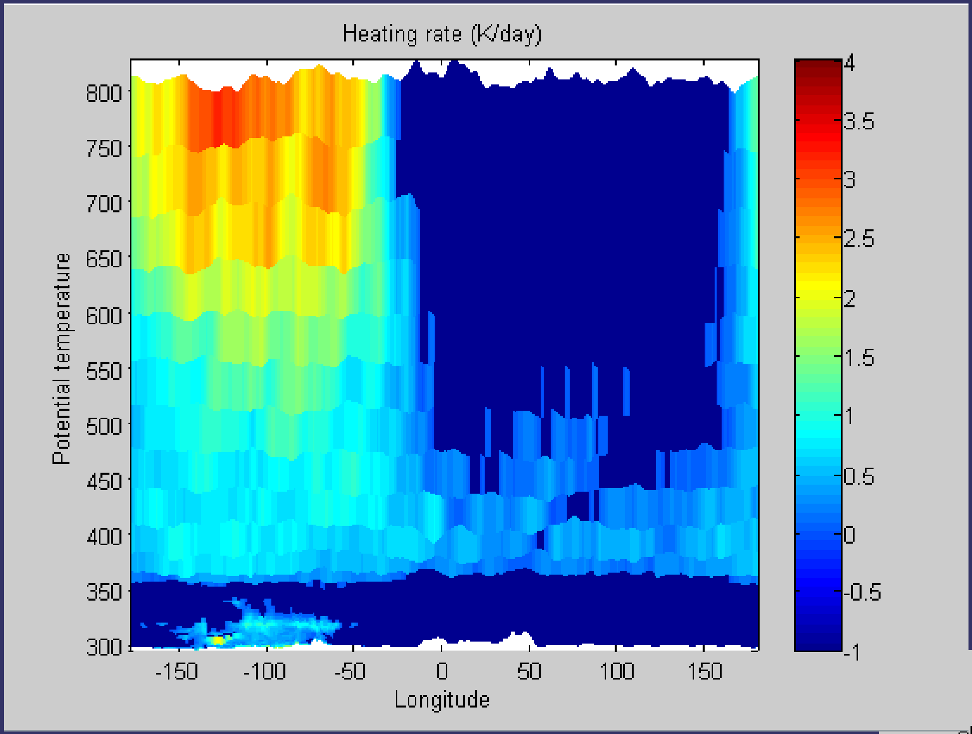


01 July 2005, 18UT, 80E

LW heating in the top of the TTL

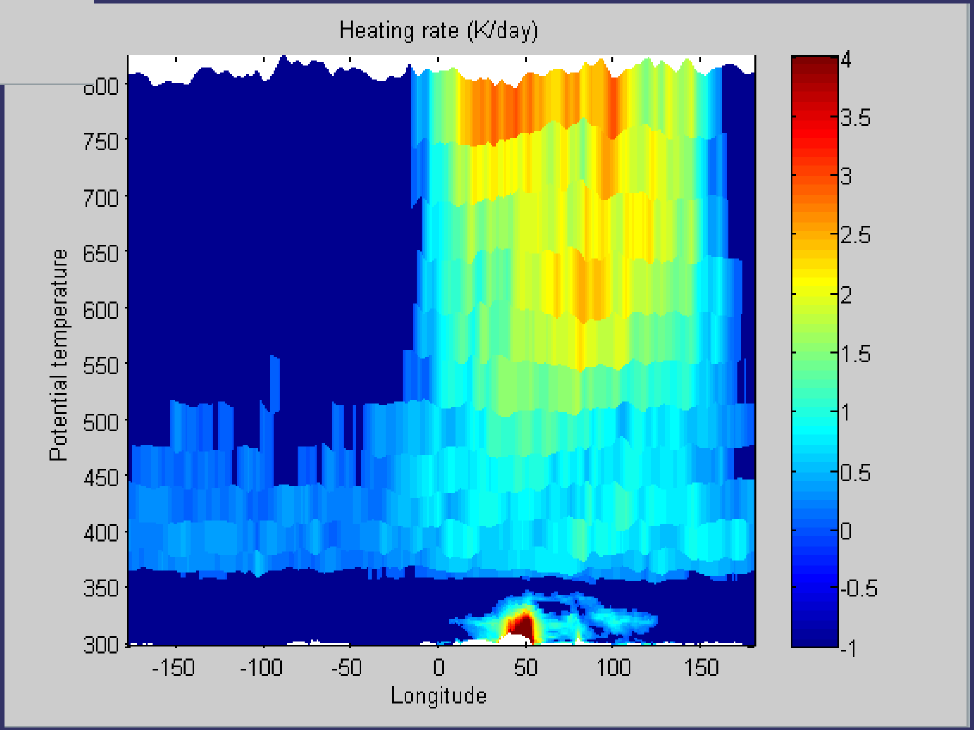
ERA-Interim data

Distribution of 3-hourly clear sky heating rate Longitudinal sections at 20N



01 July 2005, 18 UT, 10N

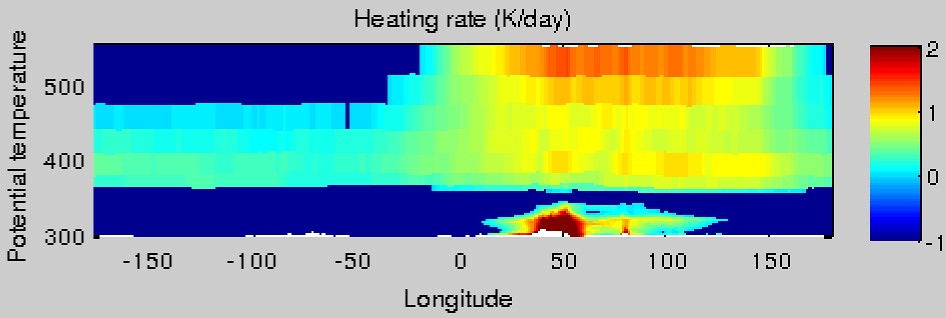
01 July 2005, 06 UT, 10N

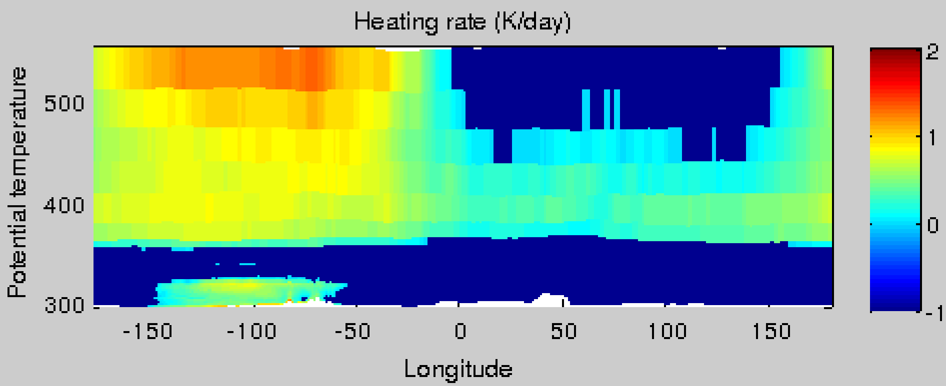


Flat longitudinal shape of the clear sky level of zero radiative heating

ERA-Interim data

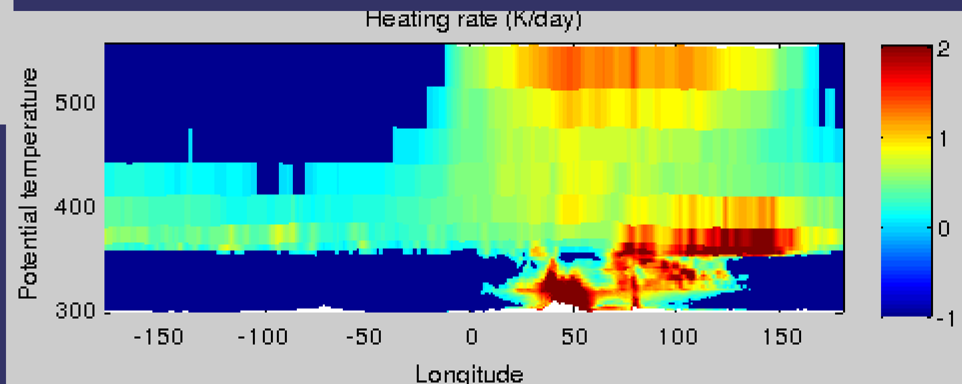
Monthly average synoptic radiative heating rates over July 2005 at 20N

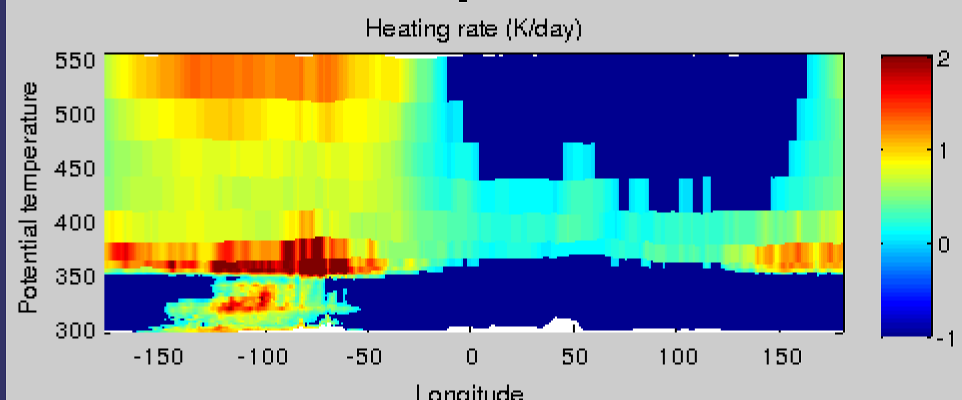




Clear sky

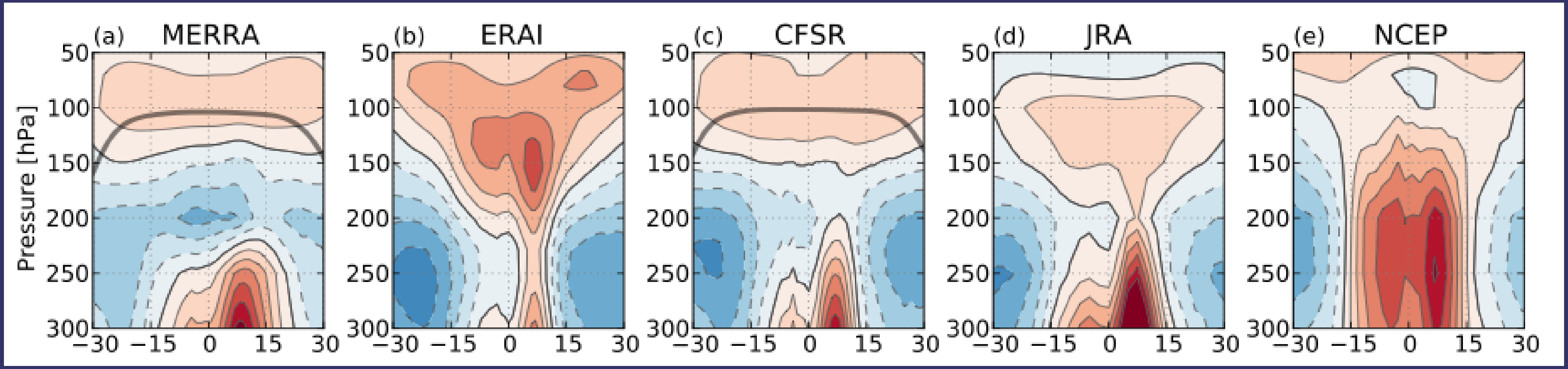
All sky including cloud radiative forcing (CRF)





The cooling barrier at the bottom of the TTL is bypassed by cloud radiative forcing

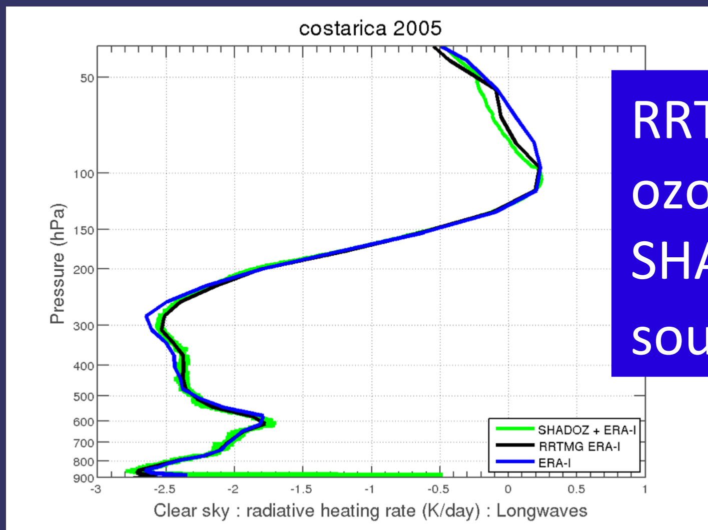
Climatological mean total diabatic heating rates (including latent heat deposition)



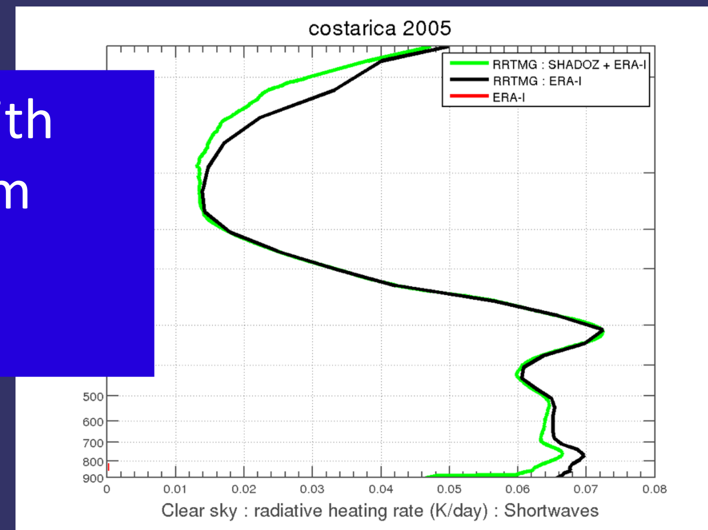
[Wright & Fueglistaler, ACP, 2013]

Large differences among reanalysis (even when ignoring the outdated NCEP).

Comparison of ERA-Interim heating with offline radiative calculation

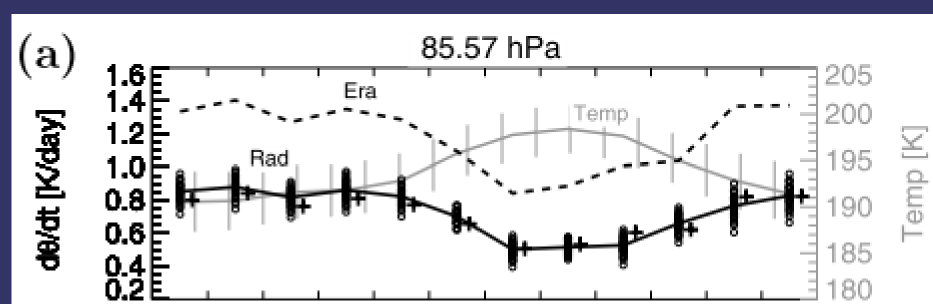


RRTMG with ozone from SHADOZ sounding

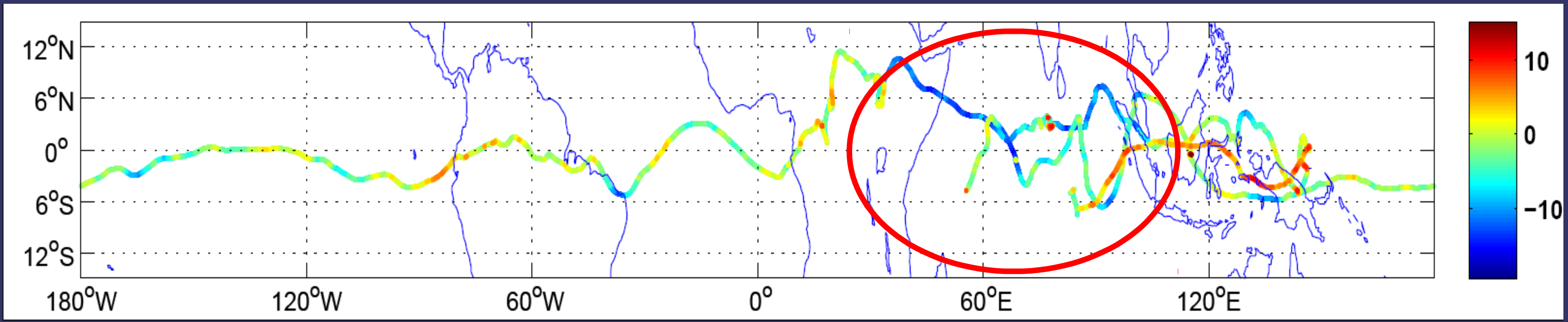


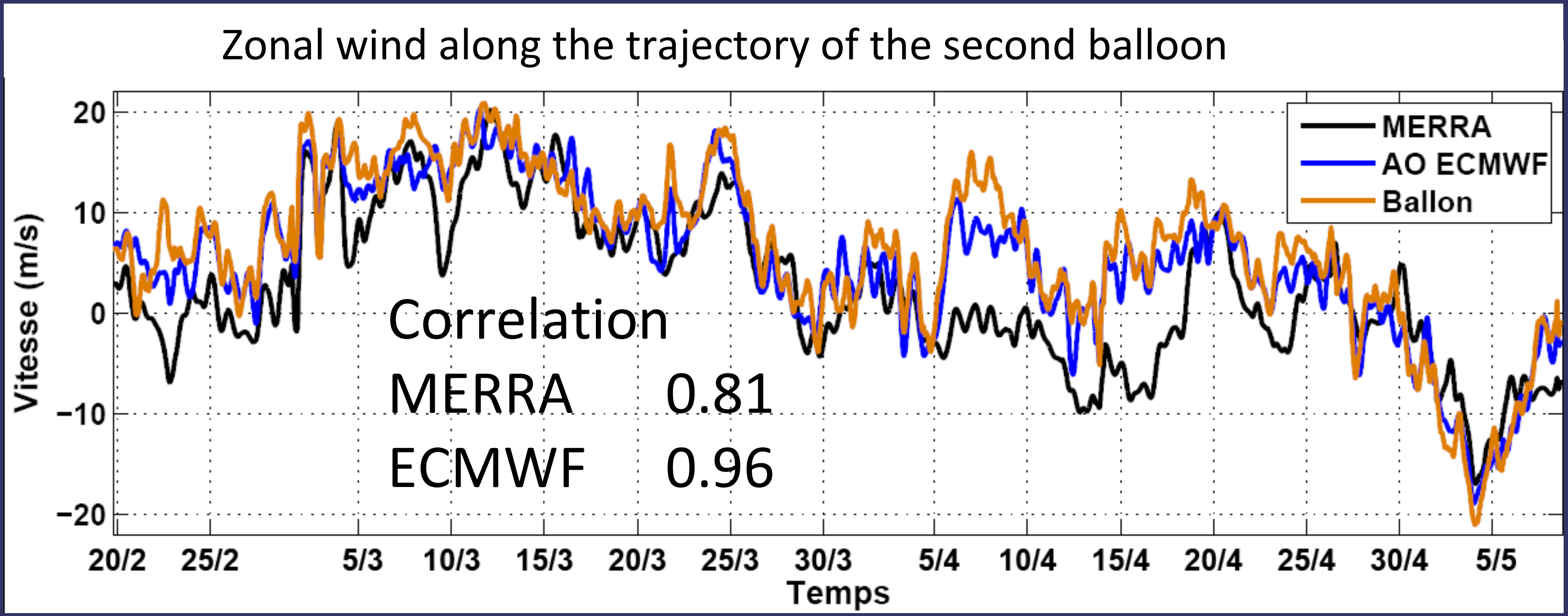
ERA-Interim clear sky heating rates show no discrepancy with offline calculations between 300 and 100 hPa but are too large at the top of the TTL above 100 hPa.

Ploeger et al., JGR, 2012
Corrective factor 0.6 at 86 hPa



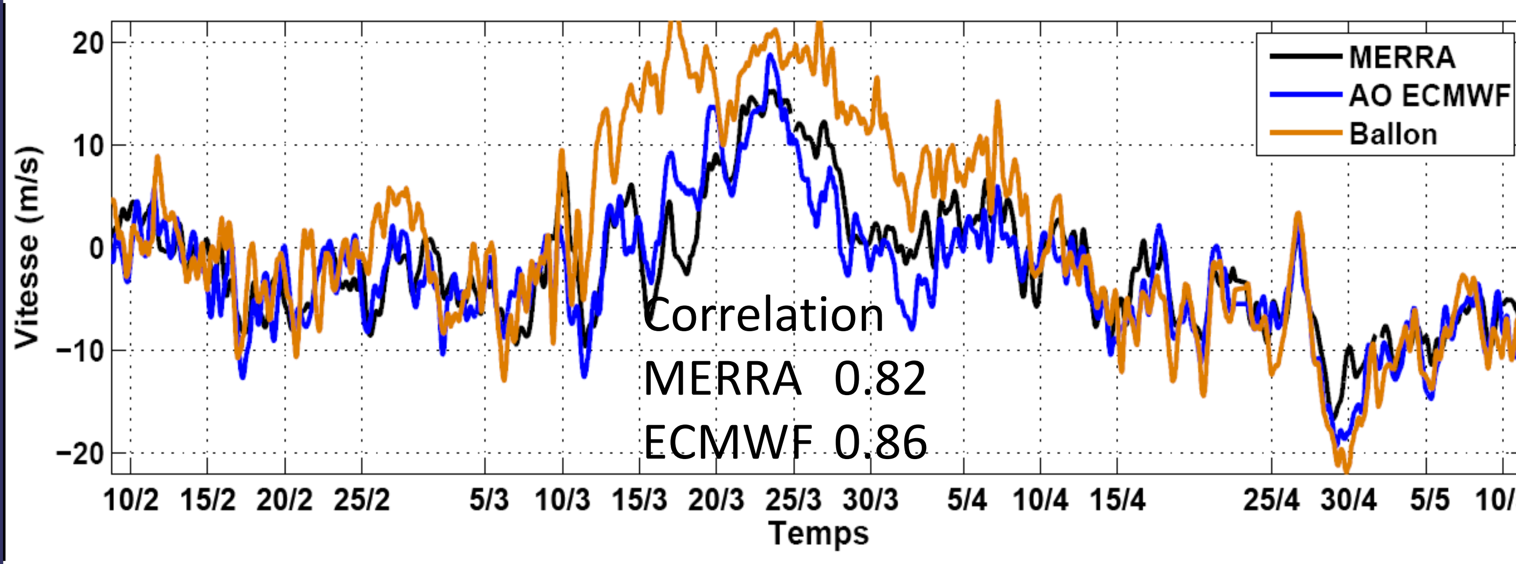
Analysed wind compared to balloon trajectory in the tropics



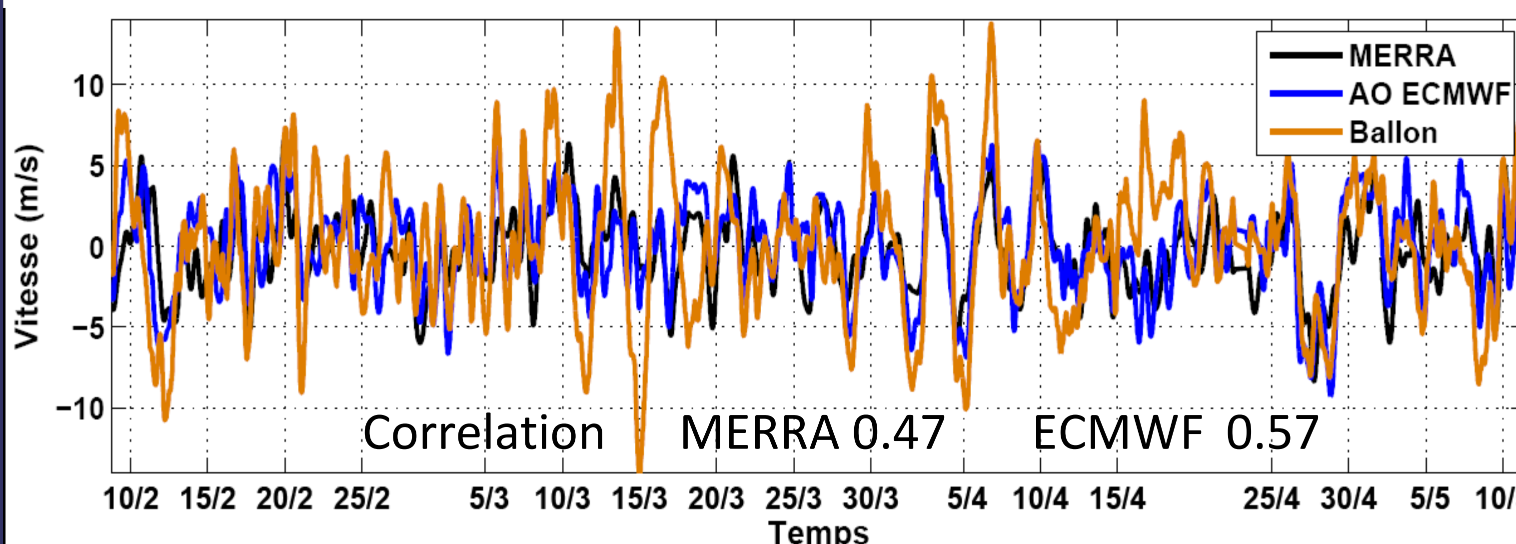


Courtesy of Podglajen, Hertzog and Plougonven, 2014

Zonal wind along the trajectory of the first balloon



Meridional wind along the trajectory of the first balloon



Courtesy of Podglajen, Hertzog and Plougonven, 2014

Convective sources

General questions

- How parcels detrained by convection are tranported in the TTL, across the level of zero heating ?
- What is the horizontal and vertical distribution of the convective sources ?
- What is the residence time of parcels within the TTL ?
- Seasonal and regional variability?

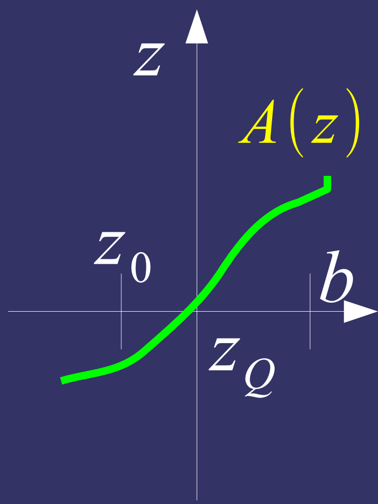
Modelling transport in the TTL from convective clouds to the stratosphere (380K) across the LZRH

→ (probability of transit, location of sources, transit times)

1D model of transport based on mean heating rate + variability as noise and vertical distribution of cloud tops

3D Lagrangian diabatic trajectories

A simple model of transport from LZRH to the tropopause



Mean heating rate

Motion: mean heating rate + noise $\delta z = A\,\delta t + B^{1/2}\,\delta w$

LZRH : $A(z_Q) = 0$

Equation for the probability $p(z, t \mid z_0, 0)$ of transit from z_0 at time 0 to z at time t

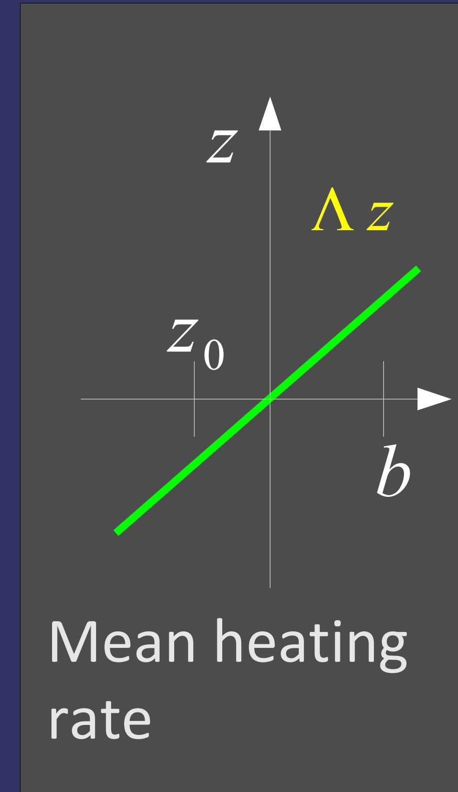
$$\partial_t p = -\partial_z A\,p + \frac{1}{2}\partial^2_{z^2} B\,p$$

This problem can be solved analytically for many interesting quantities (Gardiner, 1985).

For example, the probability to cross b (the tropopause) while starting in z_0 is $\Pi_b(z_0) = \dfrac{\int_{-\infty}^{z_0} \psi^{-1}(y)\,dy}{\int_{-\infty}^{b} \psi^{-1}(y)\,dy}$ with $\psi(y) = \exp \int^{y} \dfrac{2A(x)}{B(x)}\,dx$

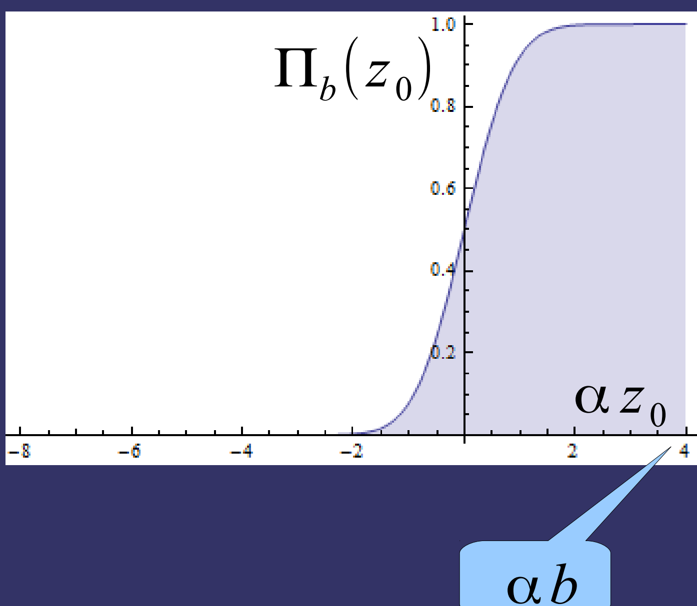
In the simplest case, when $A(z)=\Lambda z$ and $B=2\kappa$ the Fokker-Planck equation for the transit probability $p(z,t|z_0,0)$ is

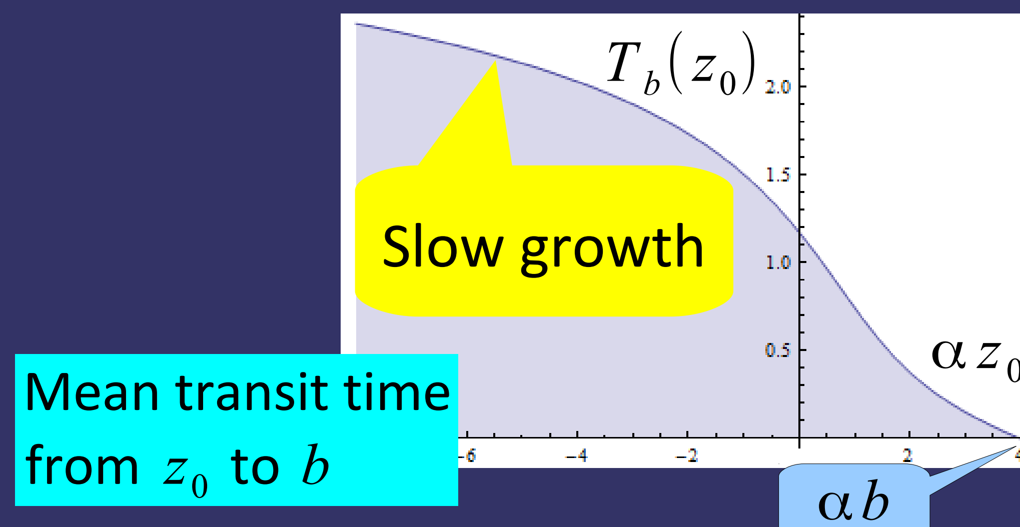
$$\partial_t p = -\partial_z \Lambda z p + \kappa \partial^2_{z^2} p$$



Probability to exit from b while starting in z_0:

$$\Pi_b(z_0) = \frac{1+erf(\alpha z_0)}{1+erf(\alpha b)} \qquad \text{with} \qquad \alpha = \sqrt{\frac{\Lambda}{2\kappa}}$$

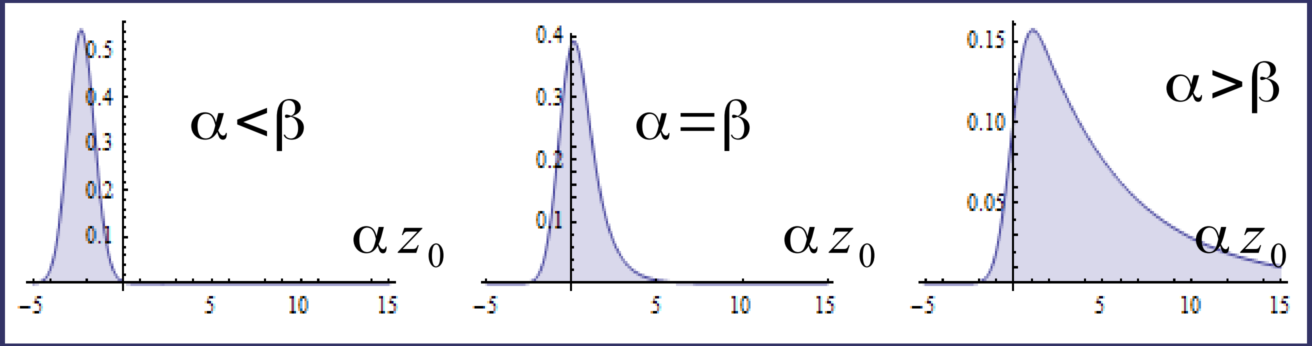




Detrainment level of clouds

Assuming an exponential distribution of convective detrainment ~ $e^{-\beta z}$,
the probability that a convective parcel reaching level b
has been detrained at level z_0 is

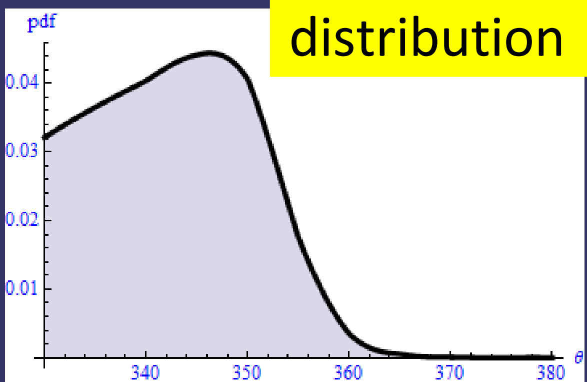
$$P(b, z_0) = \mathrm{N}^{-1} e^{-\beta z} (1 + erf(\alpha x))$$



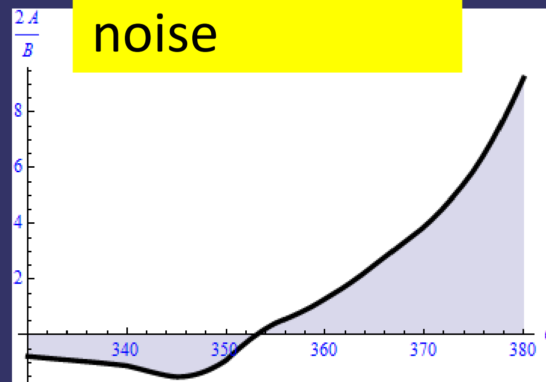
According to the ratio β/α, convective sources are below $(\beta/\alpha > 1)$ or above $(\beta/\alpha < 1)$ the LZRH

South-Asian Pacific region (warmpool) winter 2005

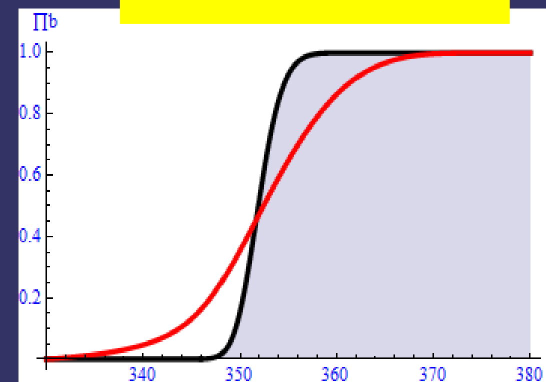
Brightness temperature distribution



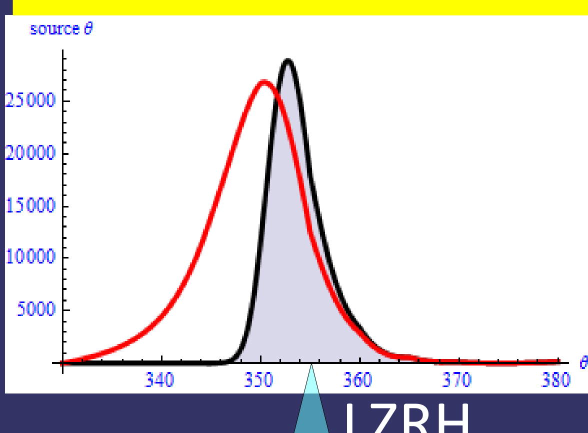
Mean heating / noise



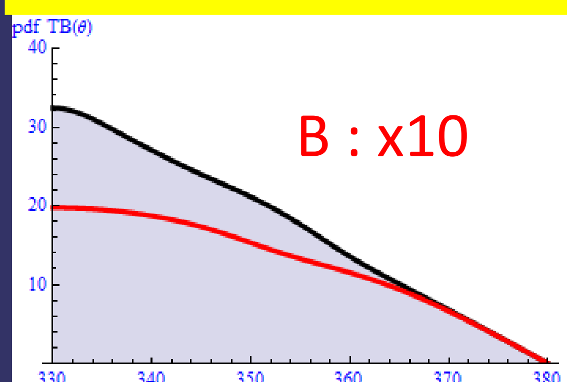
Transit probability



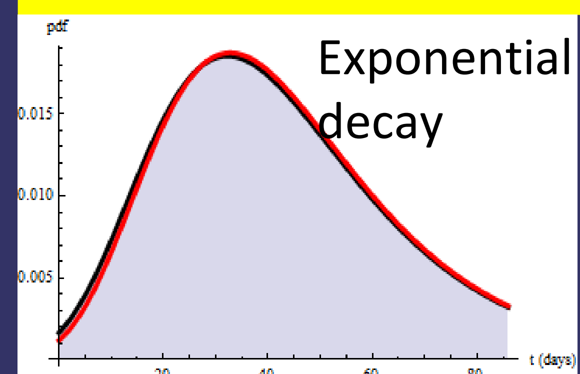
Convective source distribution of Θ



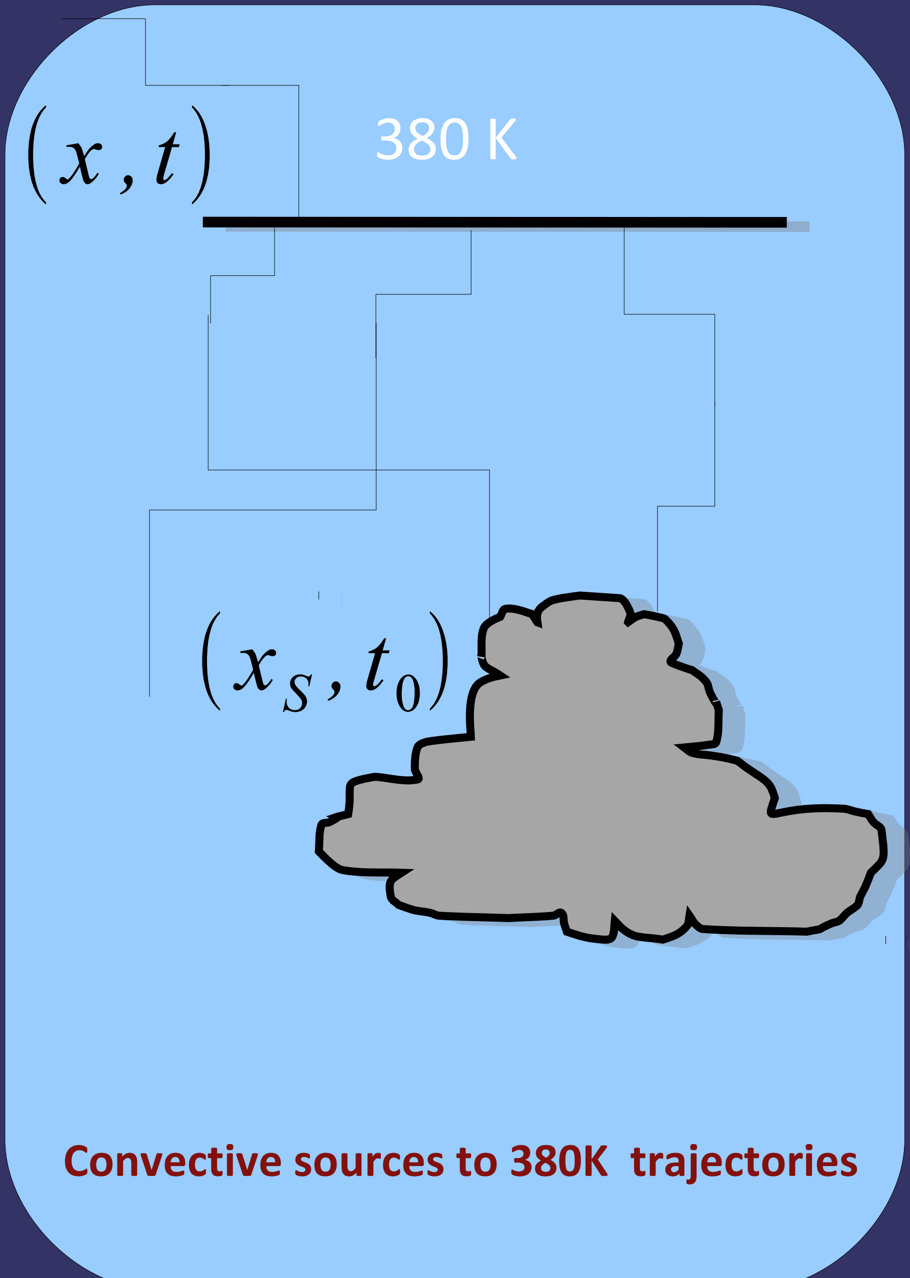
Mean transit time as a function of Θ



Distribution of transit times



Lagrangian modelling of transit from convection to tropopause

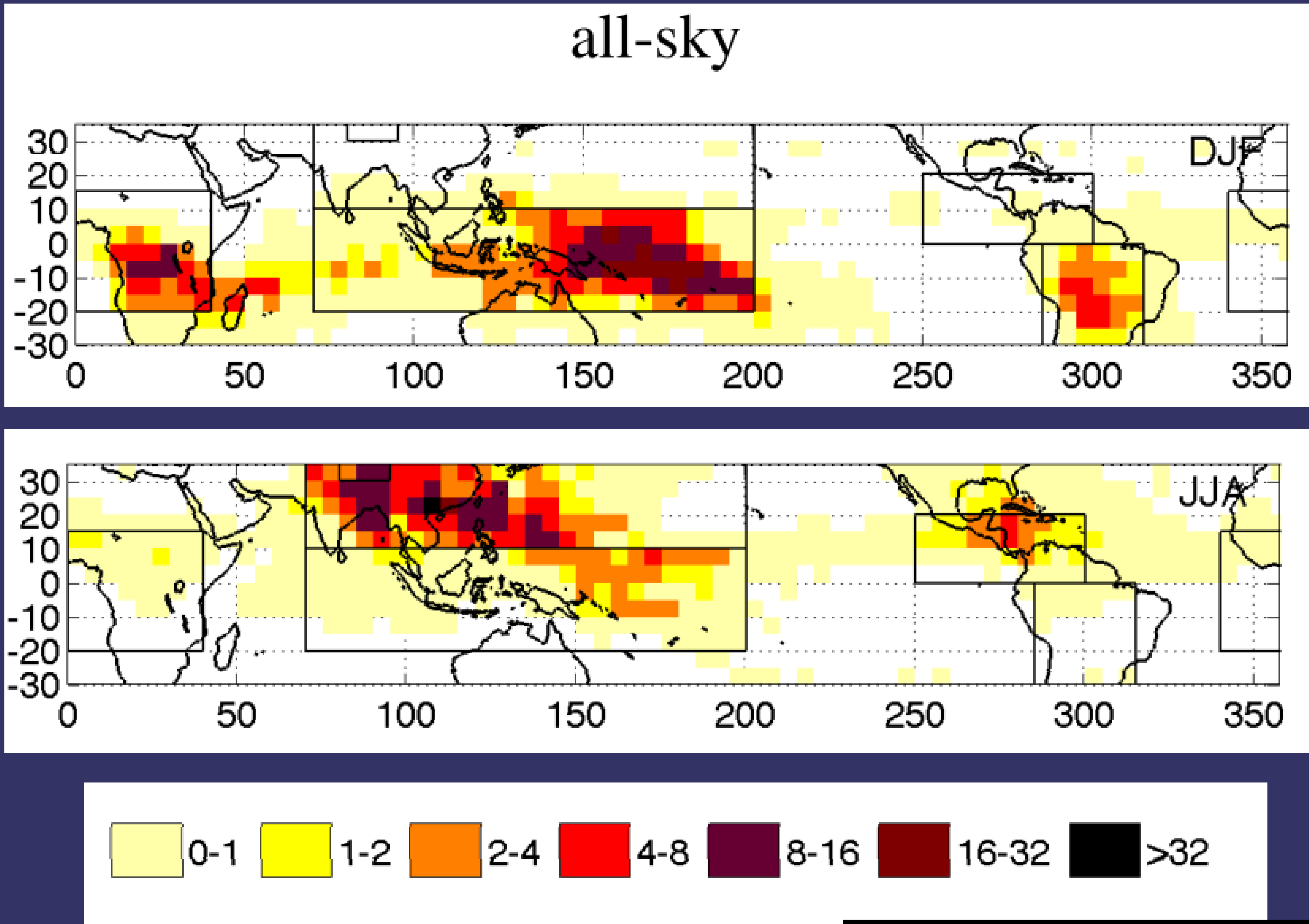


- ECMWF ERA-Interim reanalysis large-scale winds and radiative **heating rates** including the influence of clouds) to integrate trajectories
- CLAUS dataset of brightness temperature at 30km x 3h to identify cloud tops
- 1] Backward trajectories from the 380K surface until encounter of a cloud top
- → sources
- 2] Forward trajectories from cloud tops with Tb < 230 K until they encounter the 380 K surface
- → impact of convection
- 3] Forward trajectories from a space filling grid in the TTL
- → transit properties of the flow
- Simplest criterion for trajectory encountering a cloud:

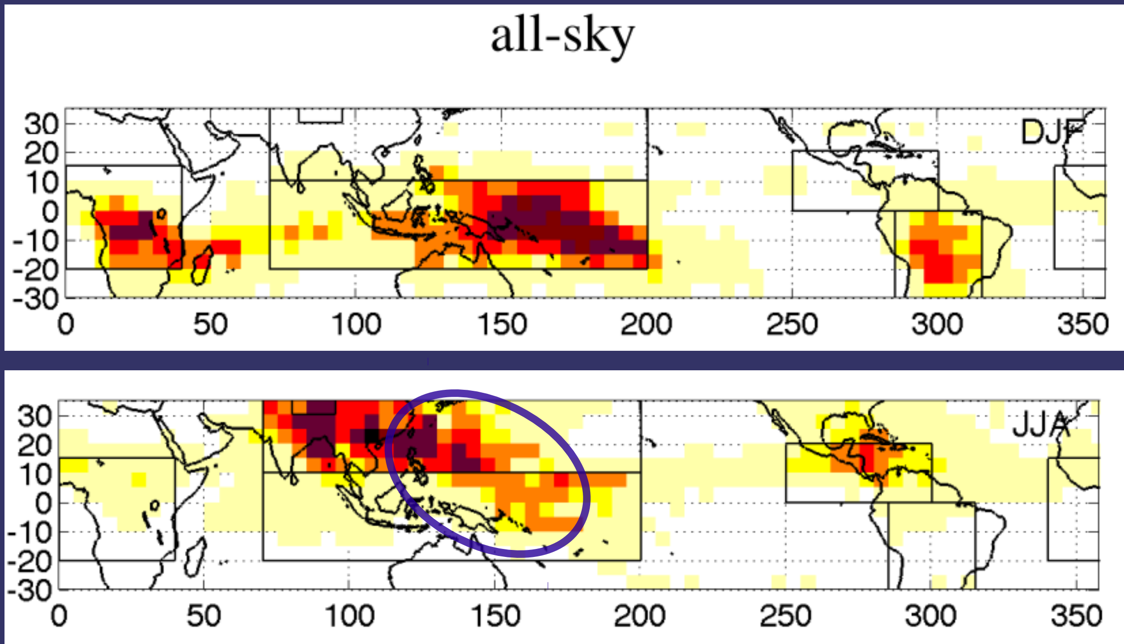
T>Tb (+ΔT)

ΔT: correction to the observed Tb accounting for altitude shift (Sherwood et al., 2004; Minnis et al., 2008)

Winter and summer distribution of all-sky sources

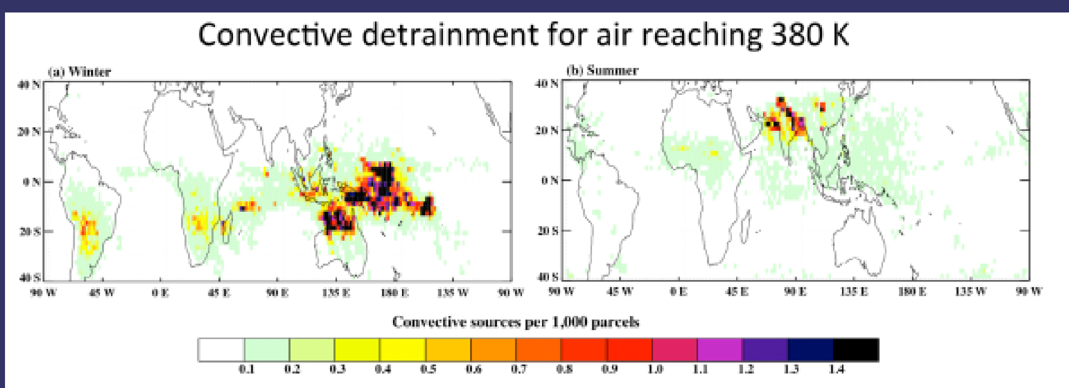


Tzella & Legras, ACP, 2011

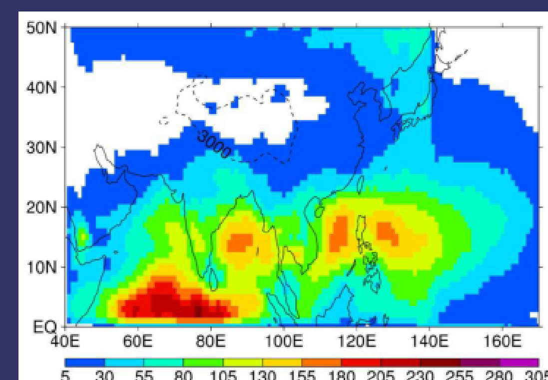


Agreement during winter (see also Krueger et al. 2008) but disagreement during summer with Bergman et al., JGR, 2011.

Chen et al., ACP, 2012 also find an important contribution above the Sea of China and the Philippines.

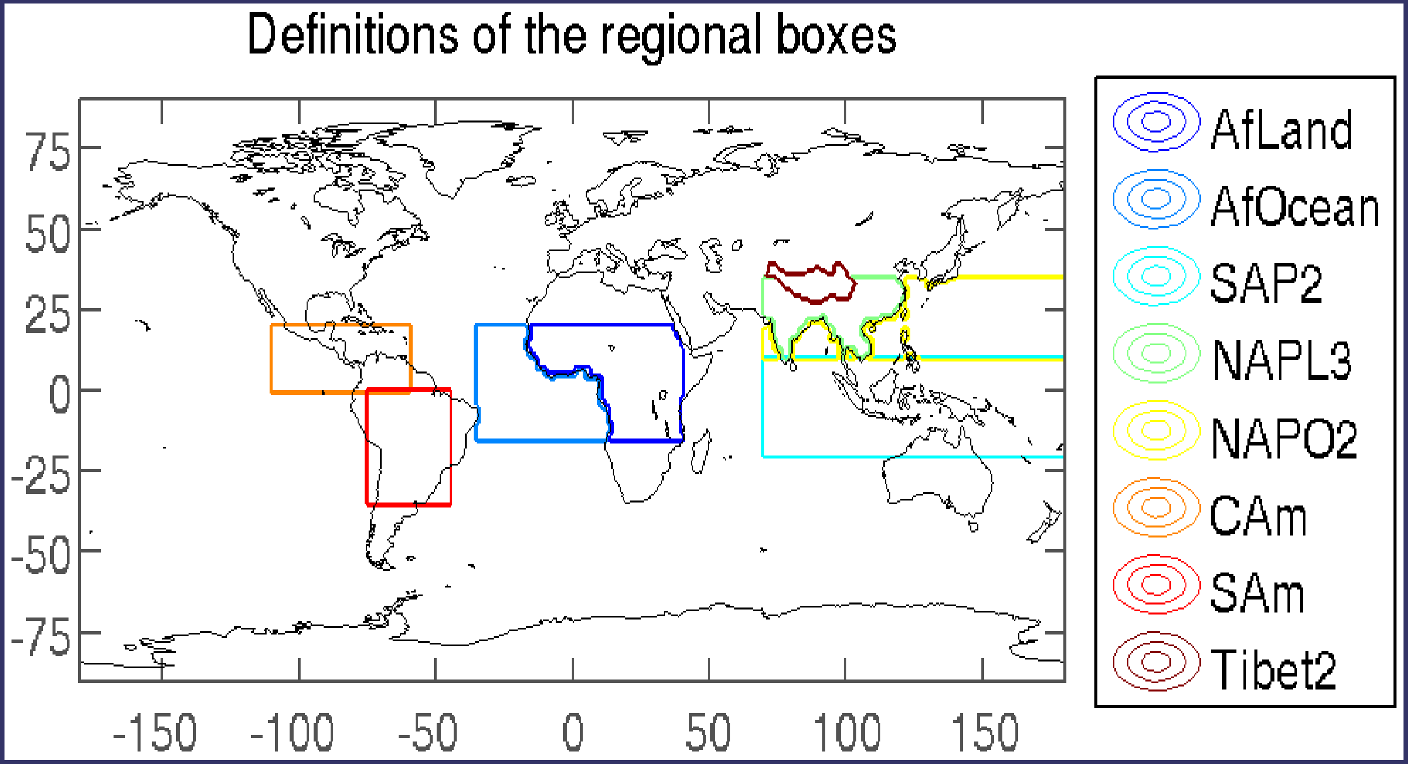


Bergman et al., JGR, 2011
Using seasonal averaged heating rates

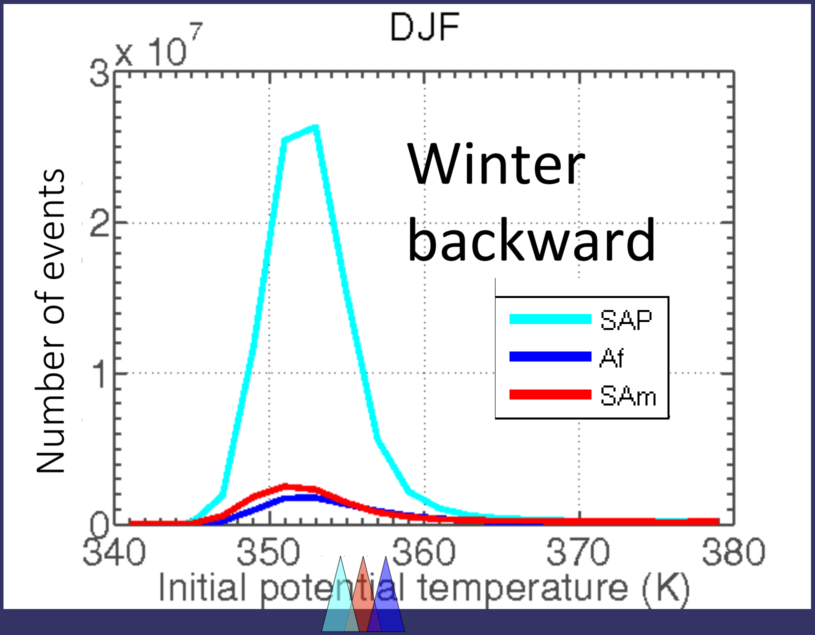


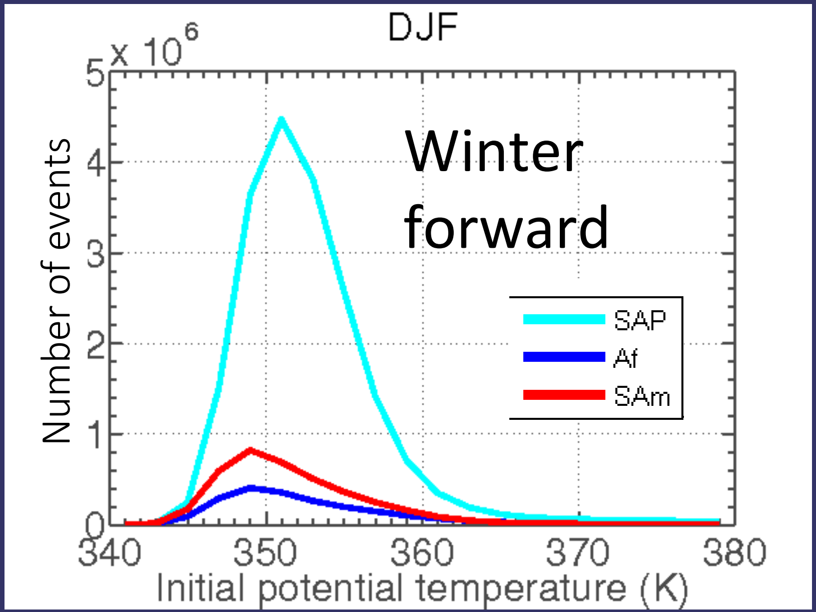
Chen et al., 2012, using NCEP/GFS winds : initial parcels in the PBL reaching the tropopause

Regional boxes are defined over the major contributing sources, separating continental from maritime convection

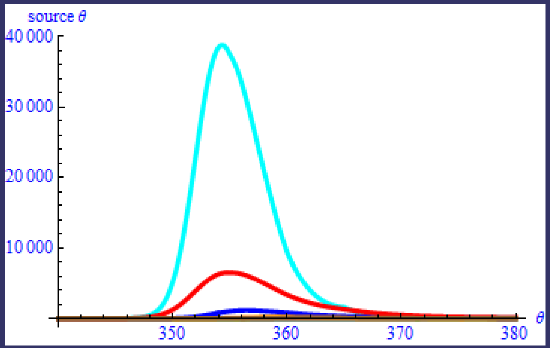


Distribution of the altitude of cloud top sources (backward) and convective impact (forward)



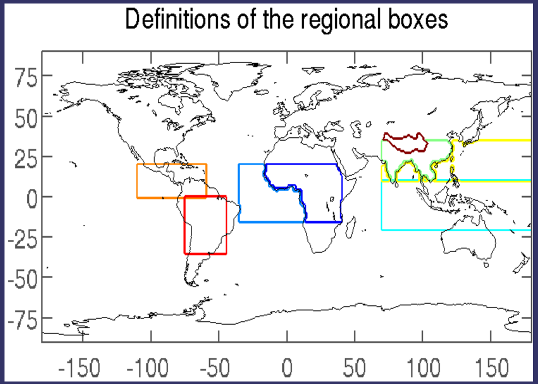


All sky LZRH

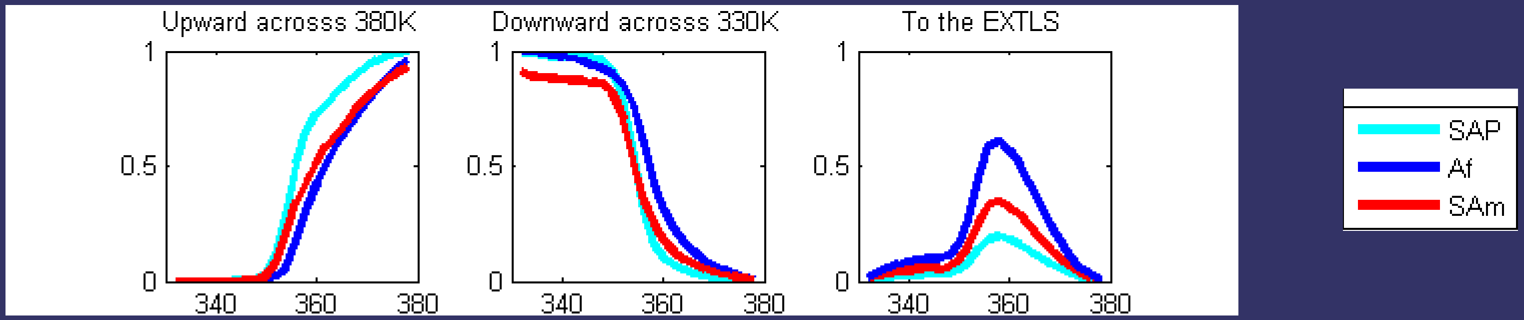


1-D model winter

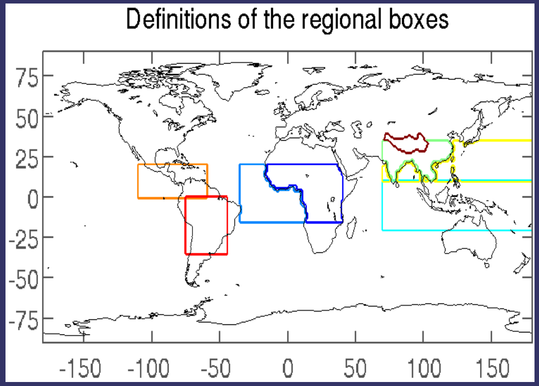
During winter most of the sources are located in the South Asian pacific region over the warmpool with minor contributions from South America and Africa. Contributed cloud tops are mostly below the all sky LZRH.



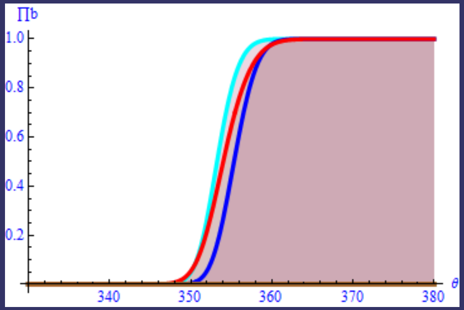
Transit properties, calculated from forward space filling trajectories (winter)



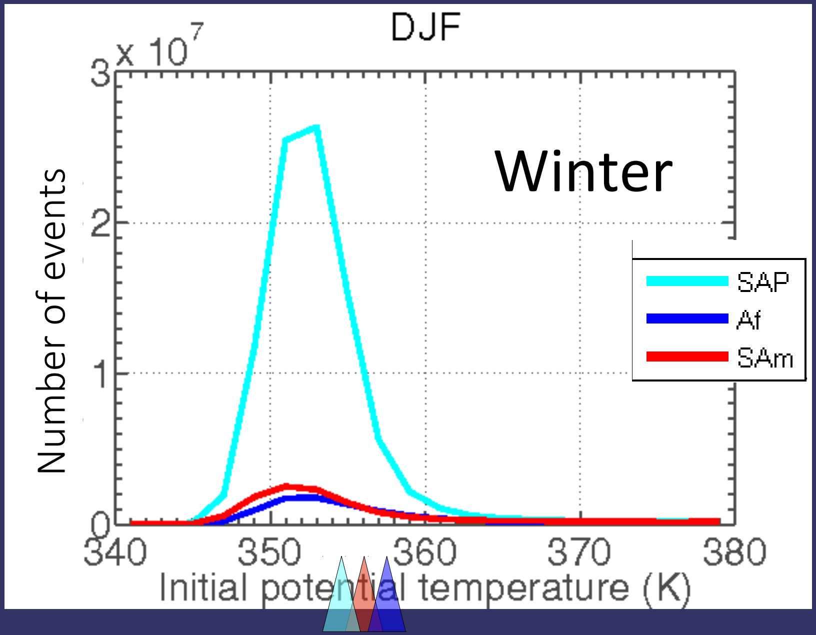
Upward transfer across the 380K surface is fairly well represented by the 1D model but for the leakage to the extratropical lowermost stratosphere (EXTLS). Trajectories from Africa and SouthAmerica are less efficient at crossing the 380K surface than from South Asia Pacific.

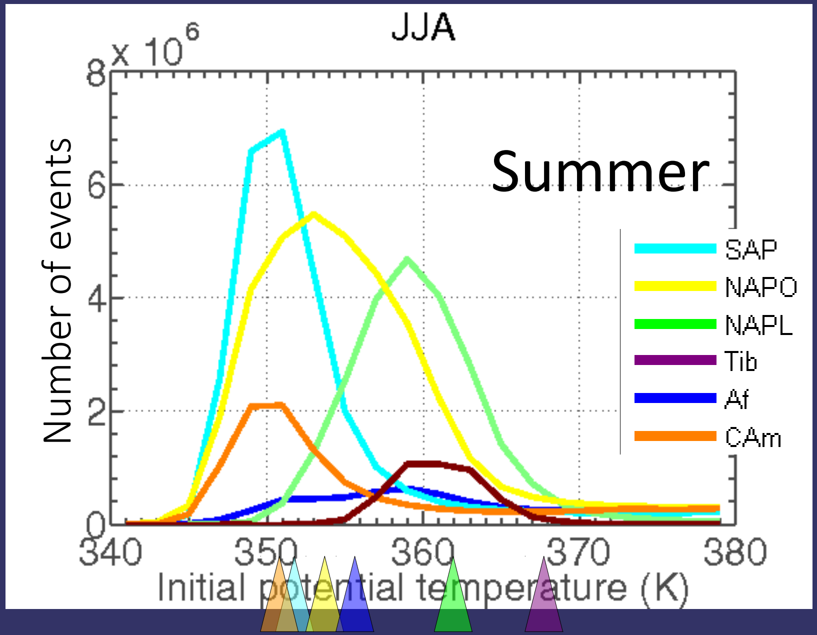


1D model

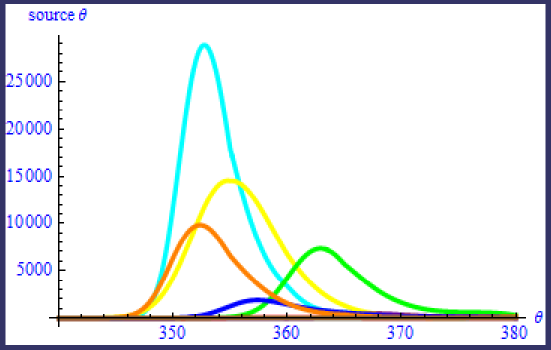


Distribution of the altitude of cloud top sources (backward)



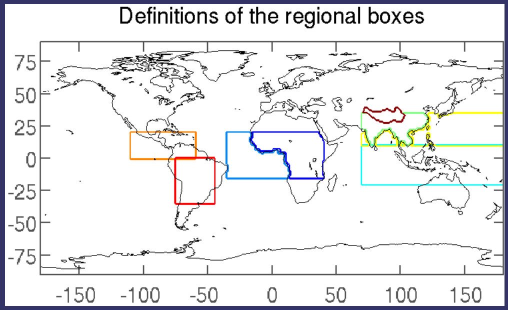


All sky LZRH

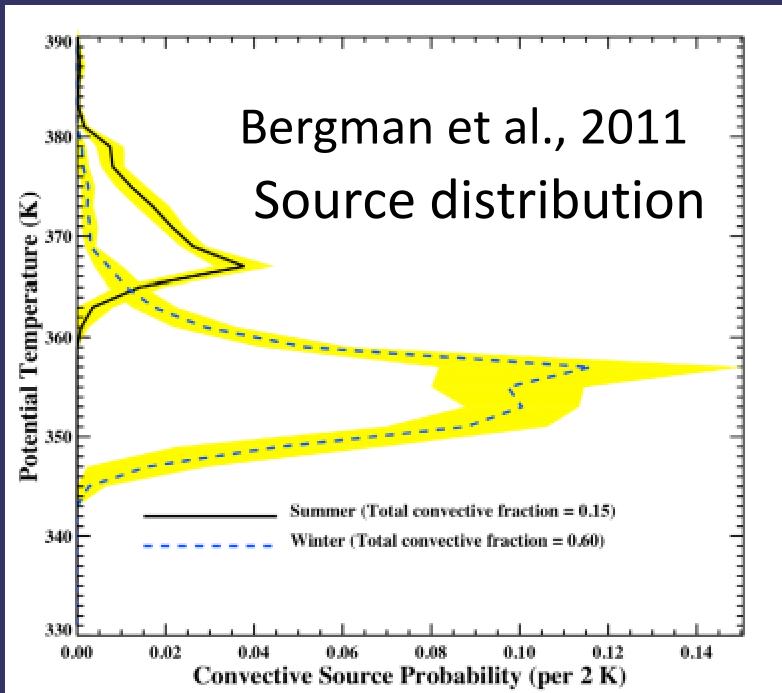


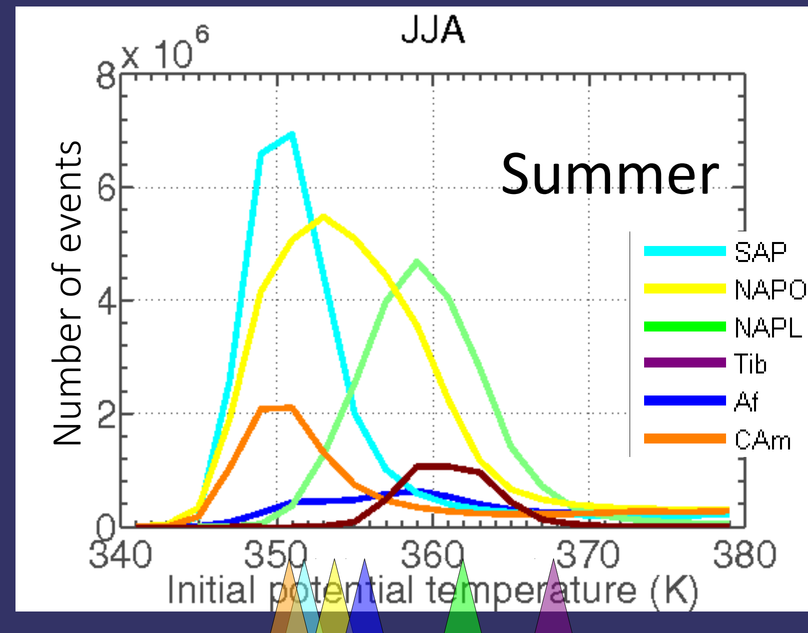
1-D model summer
Positive shift of NAPL

During summer the largest contribution is from Asian Monsoon region, both maritime (NAPO) and continental (NAPL). SAP is still important and there are minor contribution from Africa and South America. Relative to its size, the Tibetan plateau is a significant contributor. All sky LZRH is high above continental Asia.

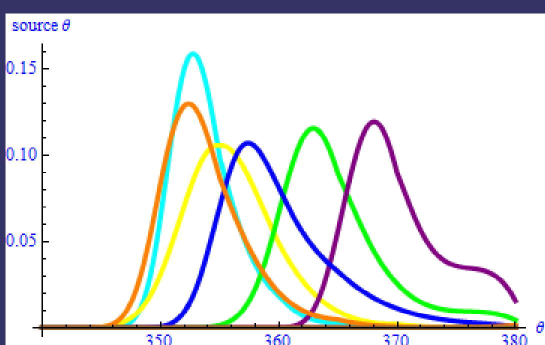


Distribution of the altitude of cloud top sources (backward)



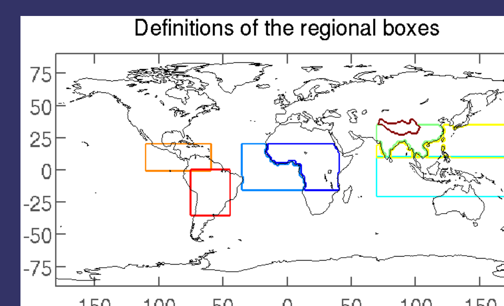


All sky LZRH

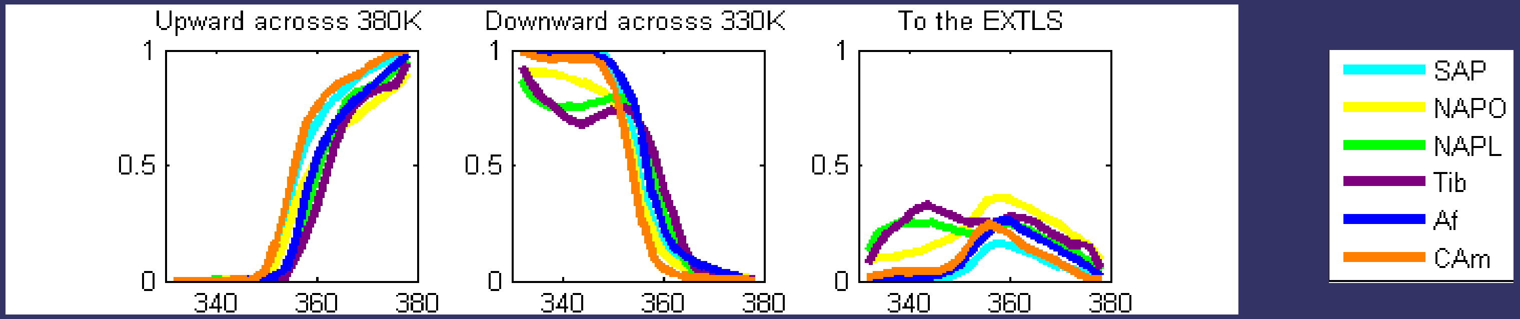


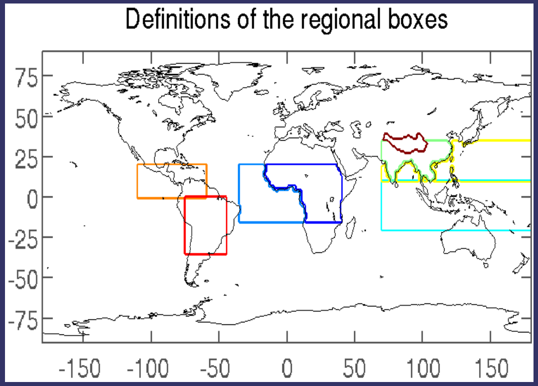
1-D model summer
Positive shift of NAPL

The mean heating rate provides Asian continental sources at altitudes higher by 5 to 10K with respect to the 3D calculations with variable heating rate.
It is important to account the time variations of the heating rate in this region.

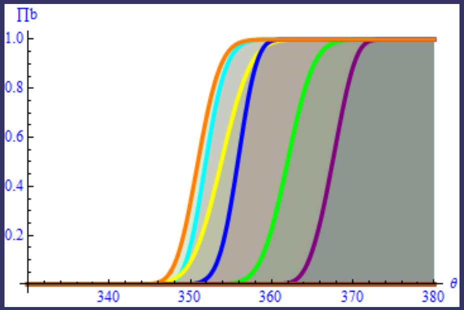


Transit properties, calculated from forward space filling trajectories (summer)

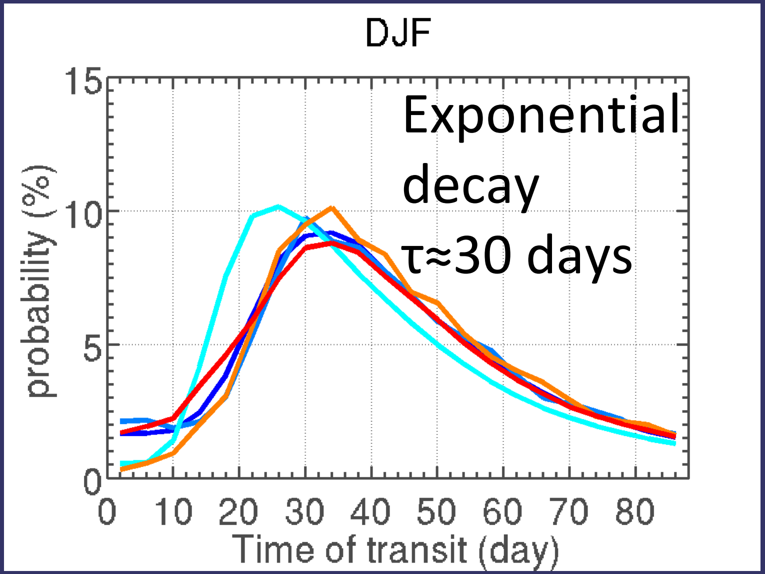


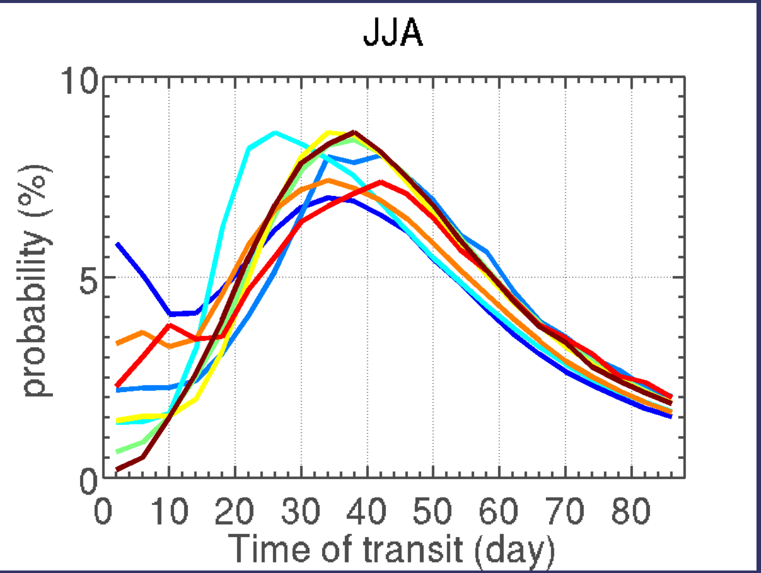


1D model



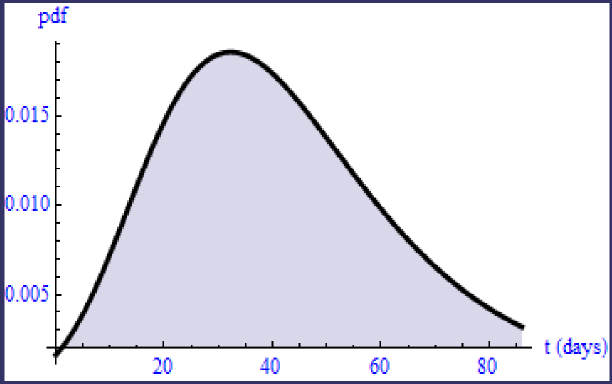
Transit times from convective cloud top to 380K

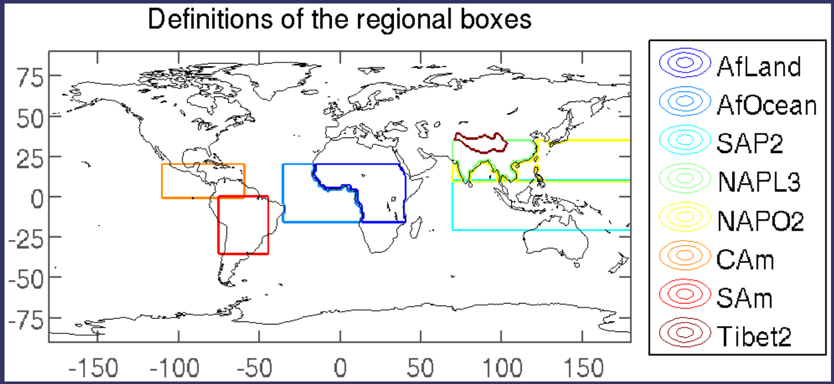




Shorter modal transit time in SAP than in any other region.
Contribution of overshooting convection during summer.
Weak seasonal variations.
Mean (40 days for SAP) differs from modal time due to exponential tail.

1D model

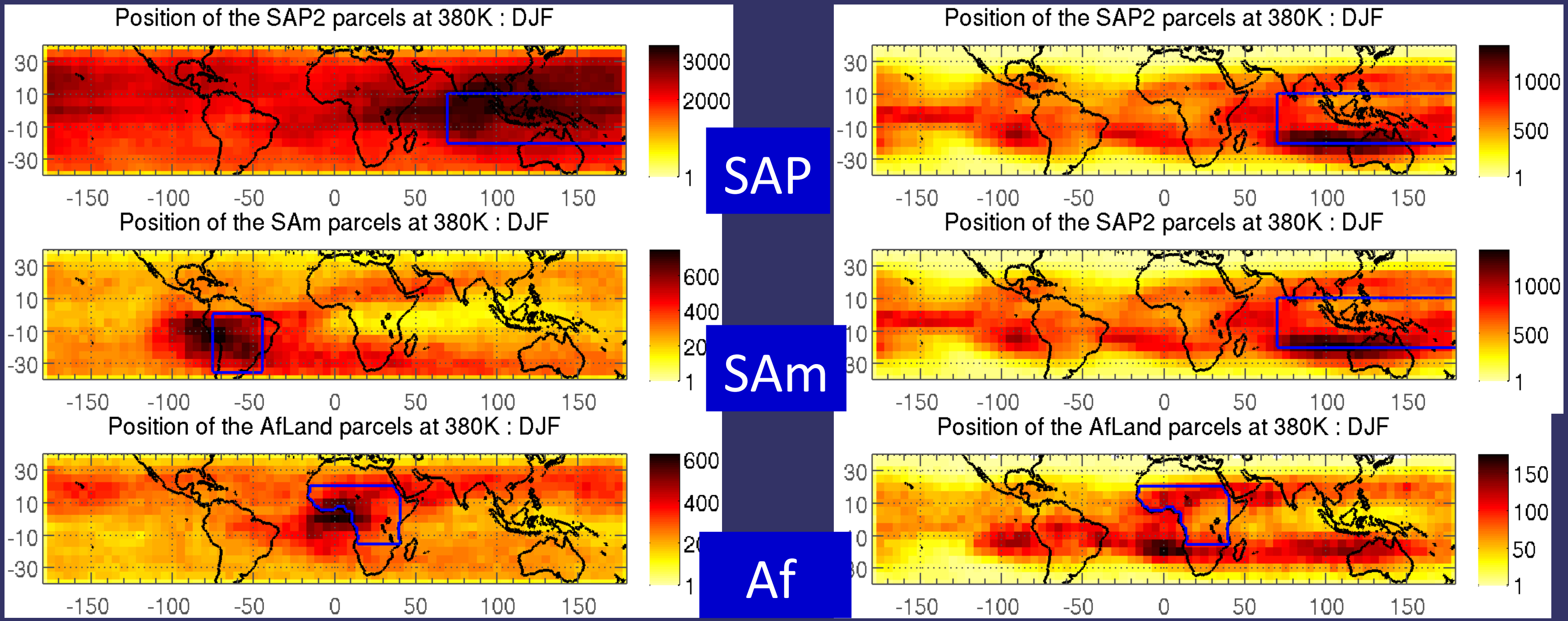




Winter (2005-2008)

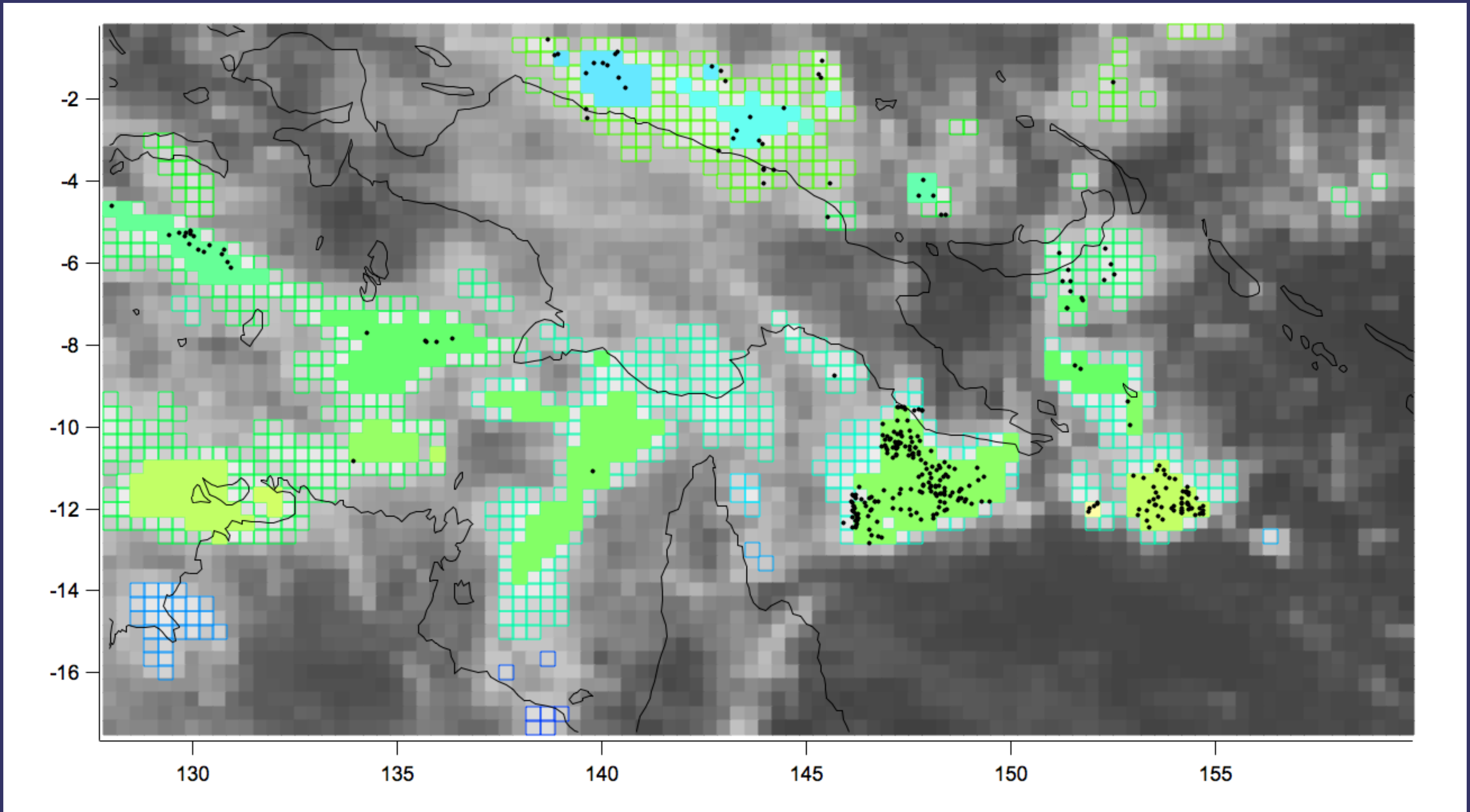
Location of coud parcels at 380K in backward and forward trajectories for the main contributing regions

Backward | Forward



Localisation of sources on a given day over the Bay of Carpentaria

Courtesy of J.P. Duvel, 2013

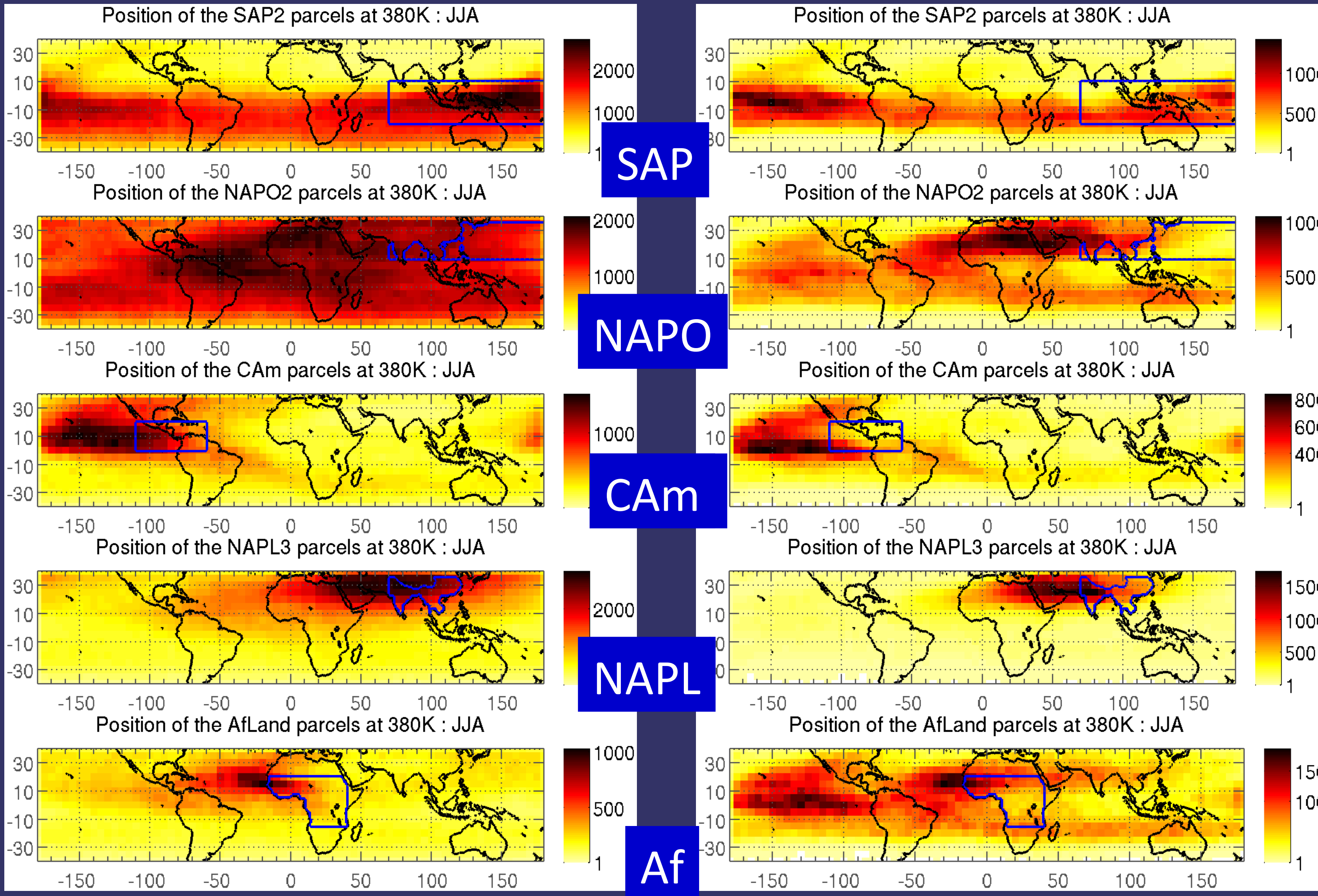


Only some convective systems contribute parcels that will reach the tropopause

Summer (2005-2008)

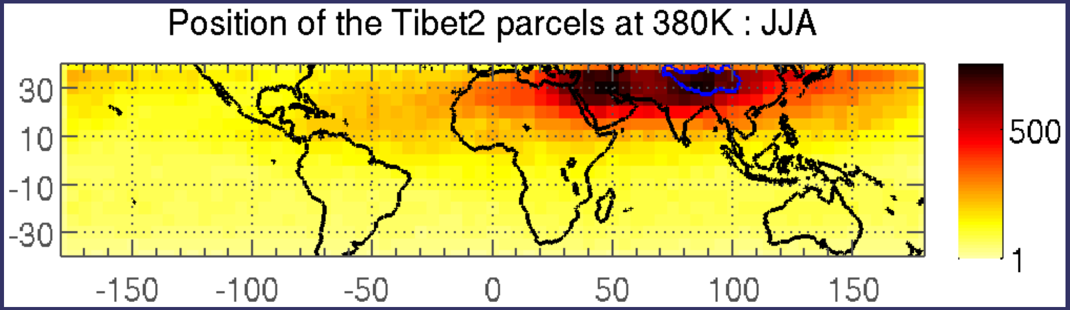
Backward

Forward

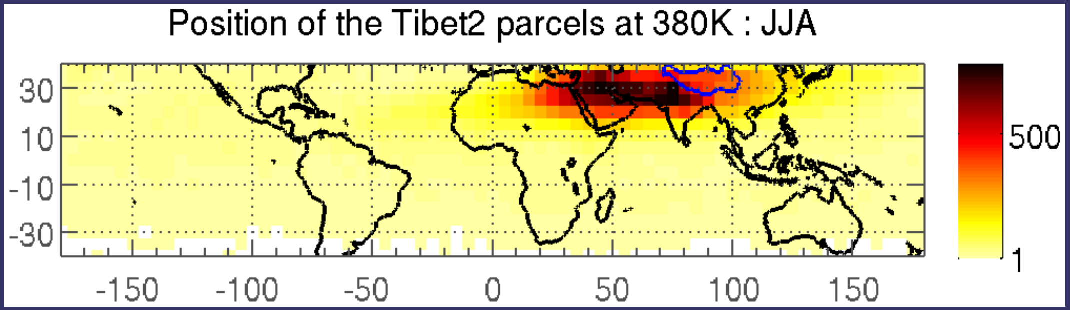


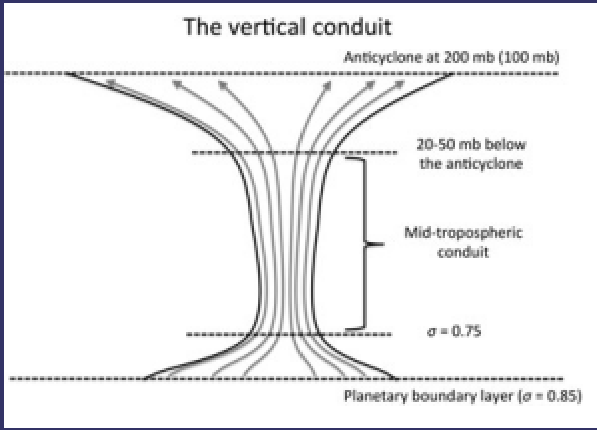
During summer, the Tibetan plateau;in spite of its small total contribution is the most efficient region in transporting air parcels from cloud top to 380K.

Backward



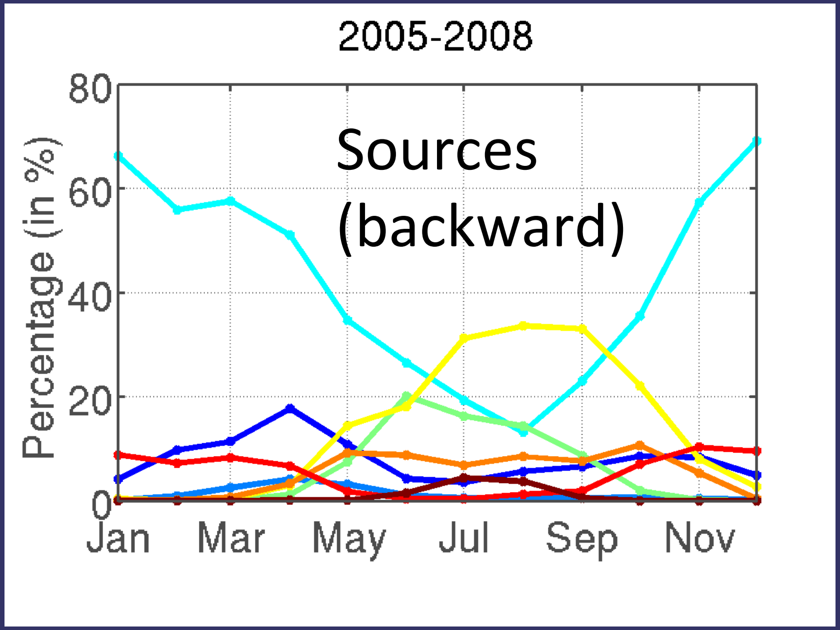
Forward

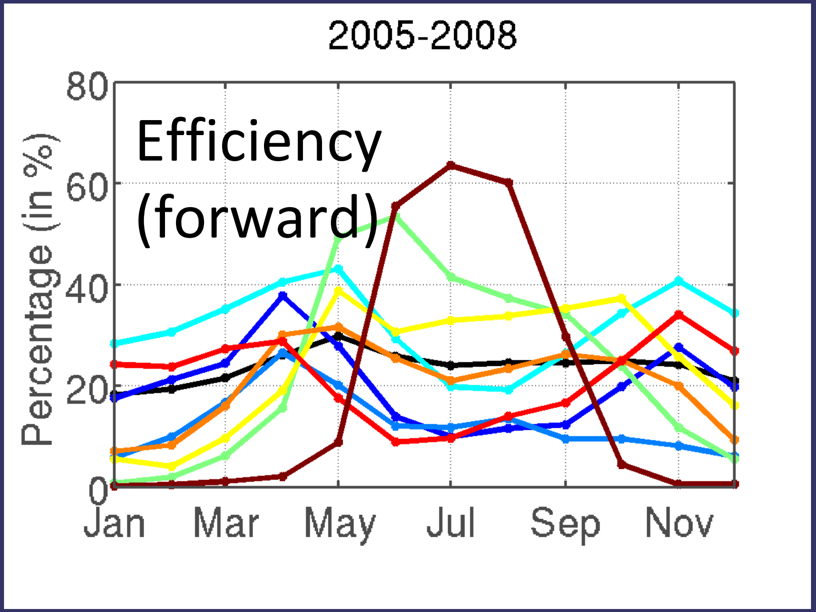




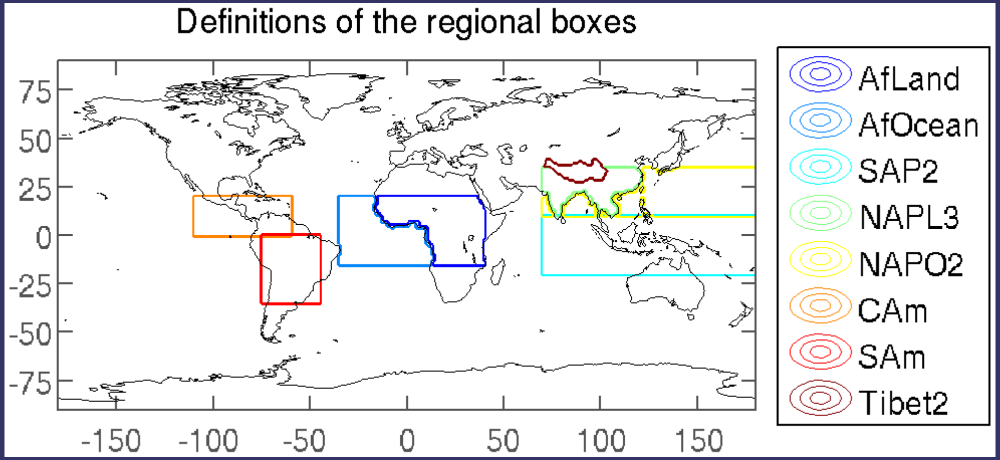
Bergman et al., ACP 2013

Convective sources and efficiency





Maritime convection always dominates among the sources. Strong efficiency of continental Asia during Summer.



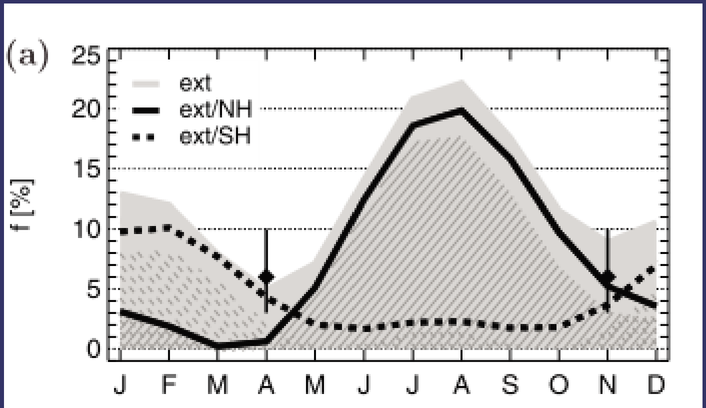
A Proportion of parcels reaching 380K from a region (forward)
B Number of 40x40km pixels with BT < 230K (per month)
C Part of the region among the sources (backward)

Region	A (%) DJF	B (10^5) DJF	C (%) DJF	A (%) JJA	B (10^5) JJA	C (%) JJA
South Asia Pacific (SAP)	31.1	6.34	63.8	22.8	4.05	19.7
Asian Monsoon Ocean (NAPO)	8.6	0.47	1.1	32.5	2.83	27.7
Asian Monsoon Land (NAPL)	2.8	0.11	0.0	44.1	1.23	17.7
South America (SAm)	25.0	1.55	8.5	10.9	0.18	0.7
Central America (Cam)	8.2	0.26	0.3	23.3	1.81	8.1
Africa Land (Af)	19.5	1.10	6.3	11.8	1.31	4.5
Tibet (Tib)	0.4	0.38	0.0	59.7	0.26	3.3

Convective sources are complemented by in-mixing (especially during summer)

20 % of the parcels from the extra -tropics at the tropopause in Tzella & Legras, 2011

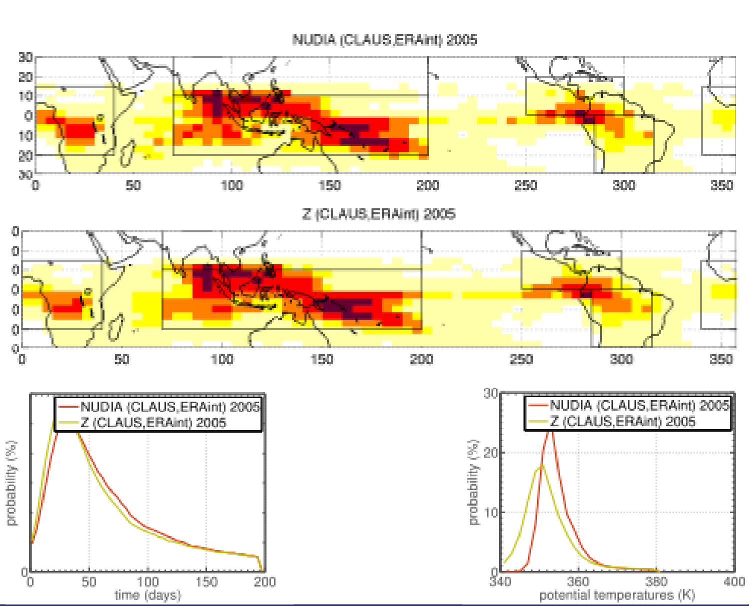
Up to 35 % in the Asian Monsoon region during summer (James et al., 2008)



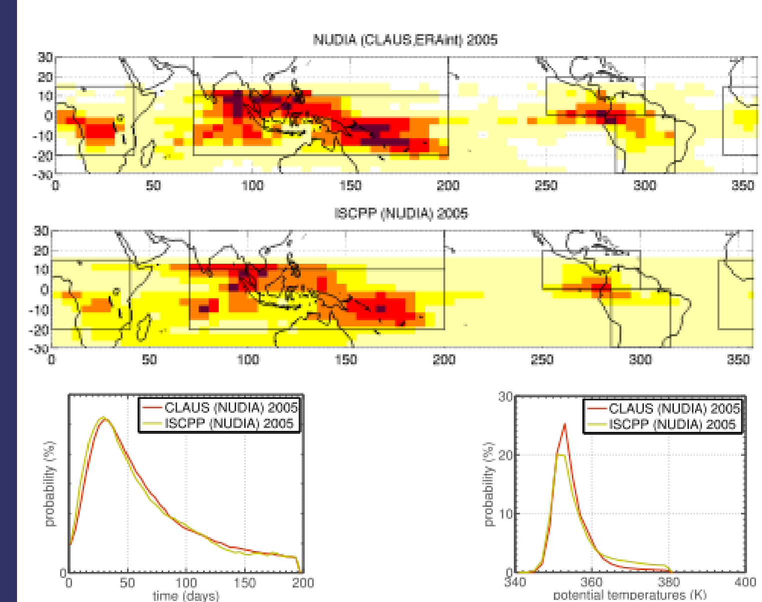
Ploeger et al., 2012
Proportion of parcels at 400K which have spent more than 5 days at latitudes higher than 50° in the last 5 months

Robustness among ECMWF world

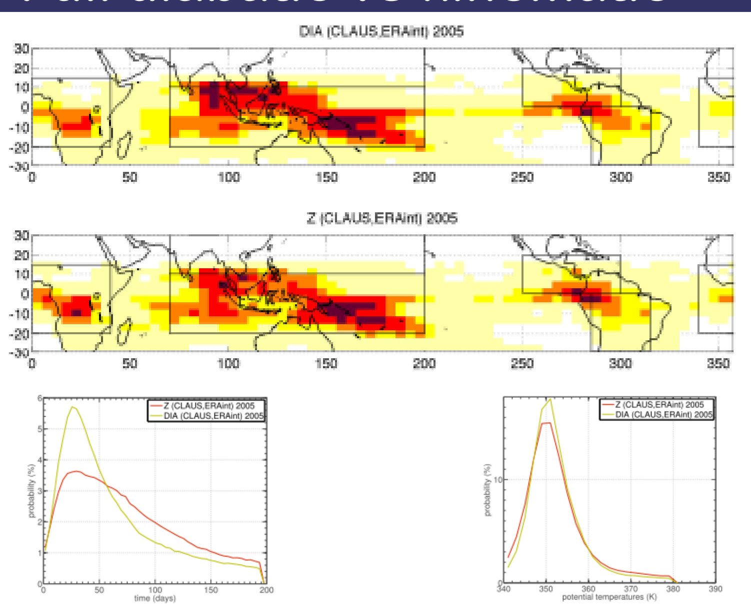
Radiative vs kinematic



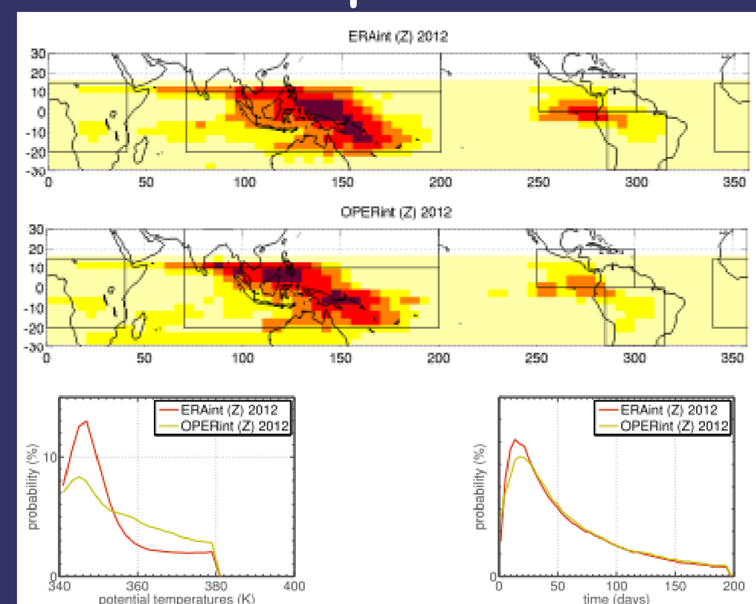
CLAUS vs ISCCP 4x4 km



Full diabatic vs kinematic



ERA-Interim vs operational 2012



Conclusion

Most of the parcels are detrained near and below the LZRH.

Long transit times are produced by parcels wandering near the LZRH

The South Asia Pacific region (warmpool) is a main contributor throughout the year and combined maritime convection always dominate the sources

Trapping within the Asian Monsoon Anticyclone is most effective for parcels released by convection over the Tibetan plateau and continental Asia north of 20N.

In mixing complements convective sources, especially during summer.

Caveats and remaining questions

Validity of reanalysed winds and heating rates

Subgrid-scale high frequency motion (increased diffusivity?).

Quantitative estimate of detrainment from convection