Lagrangian modeling of the mixing layer

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Objectives

Common sense:

...mixing is an important part of transport, in particular in vicinity of the tropopause where all relevant species have strong vertical and horizontal gradients...

- Mixing in experimental data:

  mainly manifests in tracer/tracer correlations, e.g. in CO/O_3 correlation as a deviation from an idealized L-shape (unmixed) correlation

- Mixing in the models (here in CLaMS)

  Transport = Advection (Trajectories) + Mixing (driven by deformation in the flow)

  (in most Eulerian models numerical diffusion outweighs physical mixing !)

What do we learn from START-08 and CLaMS about transport (mixing) ?

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Configuration of CLaMS:

- Multi-annual, global, run from 2001 until 1.01.2009 for the whole troposphere and stratosphere (Konopka et al, ACP, 2007)

  100 km/400 m hor/vert resolution near the tropopause

  CO/O3 with simplified chemistry

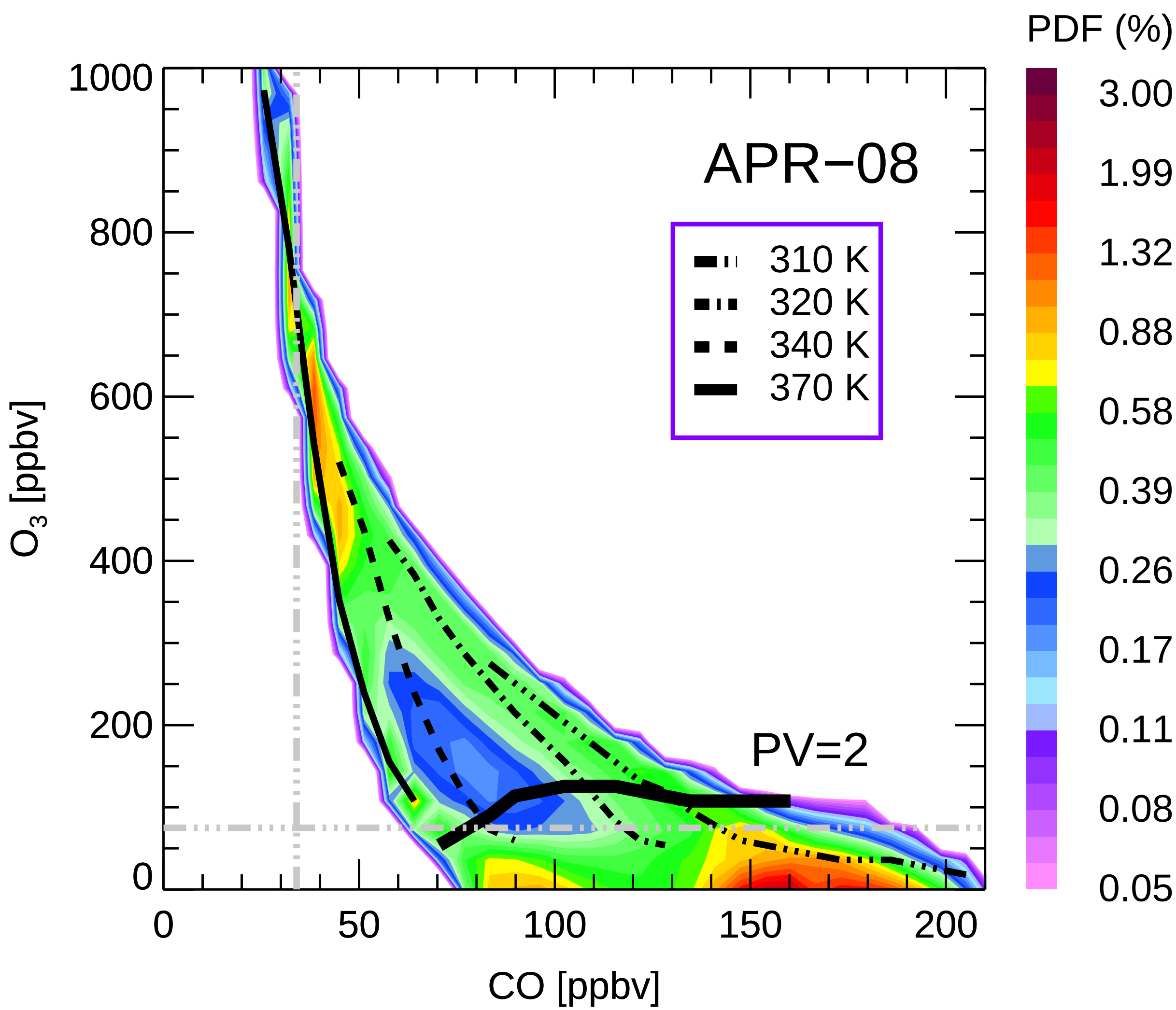
  lower boundary: O3=0, CO from MOPITT observations below 500 hPa

  O3 above $\theta = 500$ K - HALOE Climatology

  high resolution (50 km) nested runs start from the multi-annual runs about 2 weeks before the START-08 flights (Vogel et al.)

CO/O_3 correlations from CLaMS

all CLaMS air parcels with:
$lat > 25$ N, $\theta < 380$ K



CO/O_3 *correlations from CLaMS*

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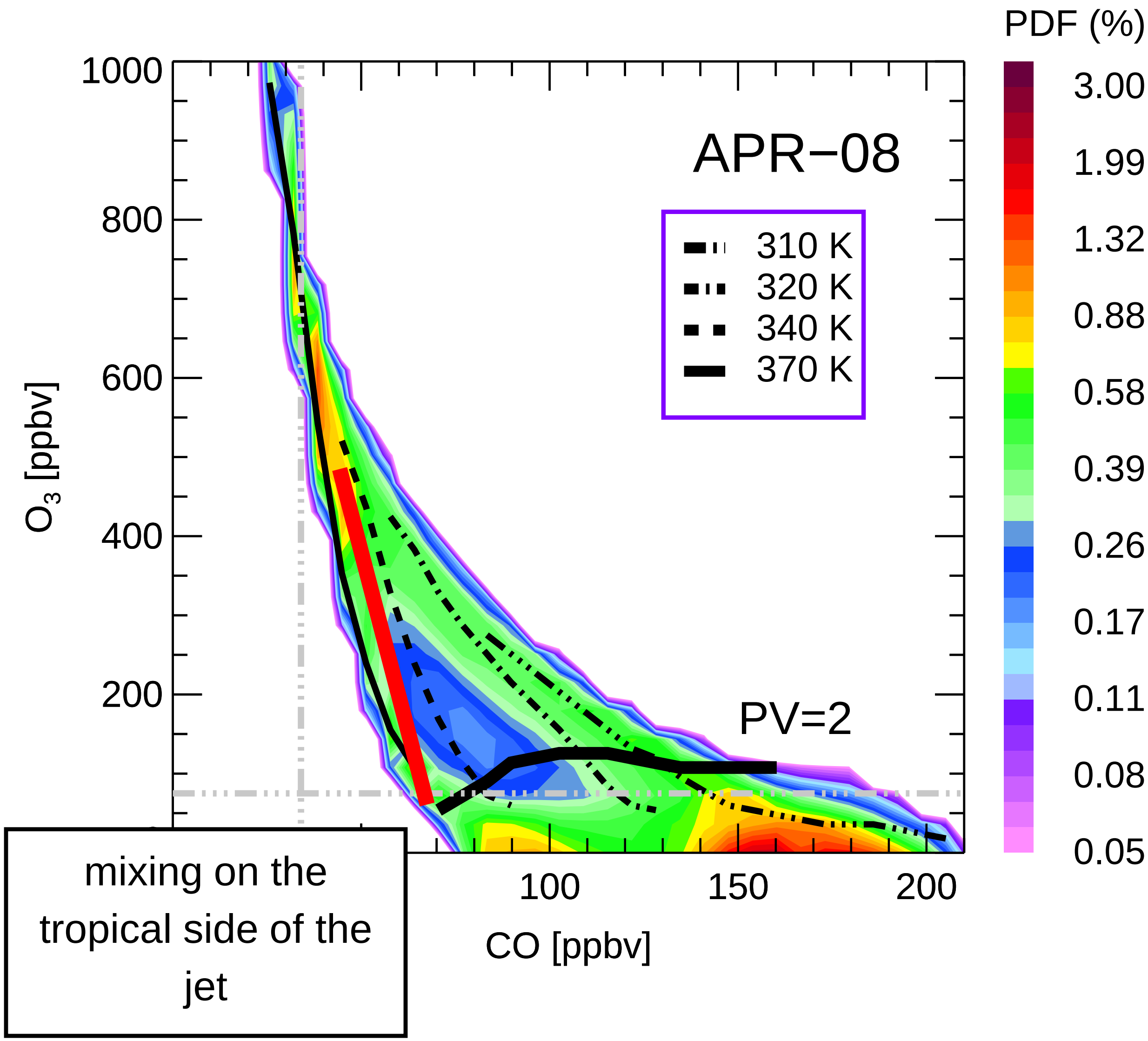
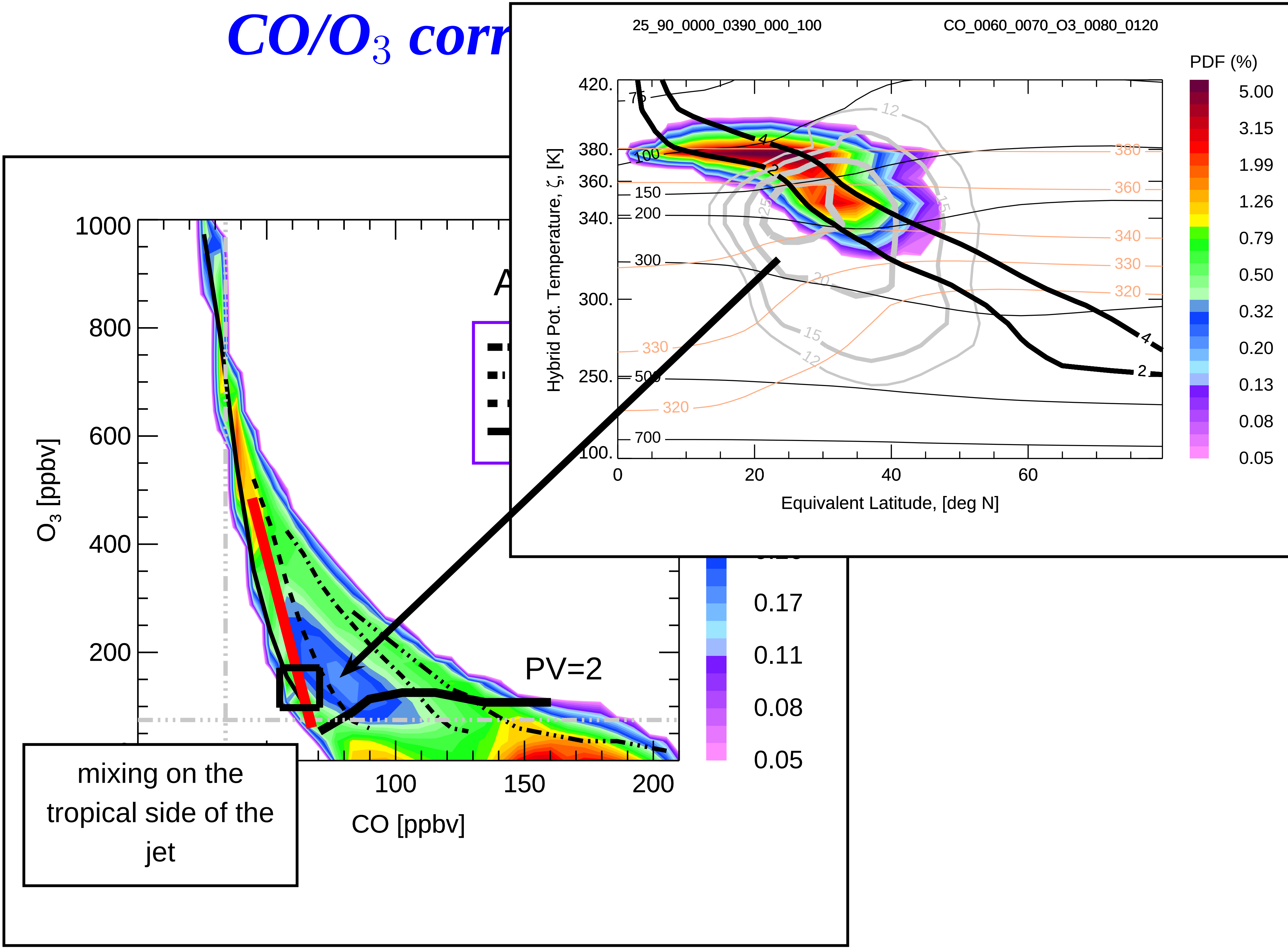


CO/O$_3$ corr



25_90_0000_0390_000_100
CO_0060_0070_O3_0080_0120
PDF (%)
5.00
3.15
1.99
1.26
0.79
0.50
0.32
0.20
0.13
0.08
0.05
Hybrid Pot. Temperature, ζ, [K]
Equivalent Latitude, [deg N]
420.
380.
360.
340.
300.
250.
100.
0
20
40
60
O3 [ppbv]
CO [ppbv]
1000
800
600
400
200
100
150
200
PV=2
0.17
0.11
0.08
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mixing on the tropical side of the jet

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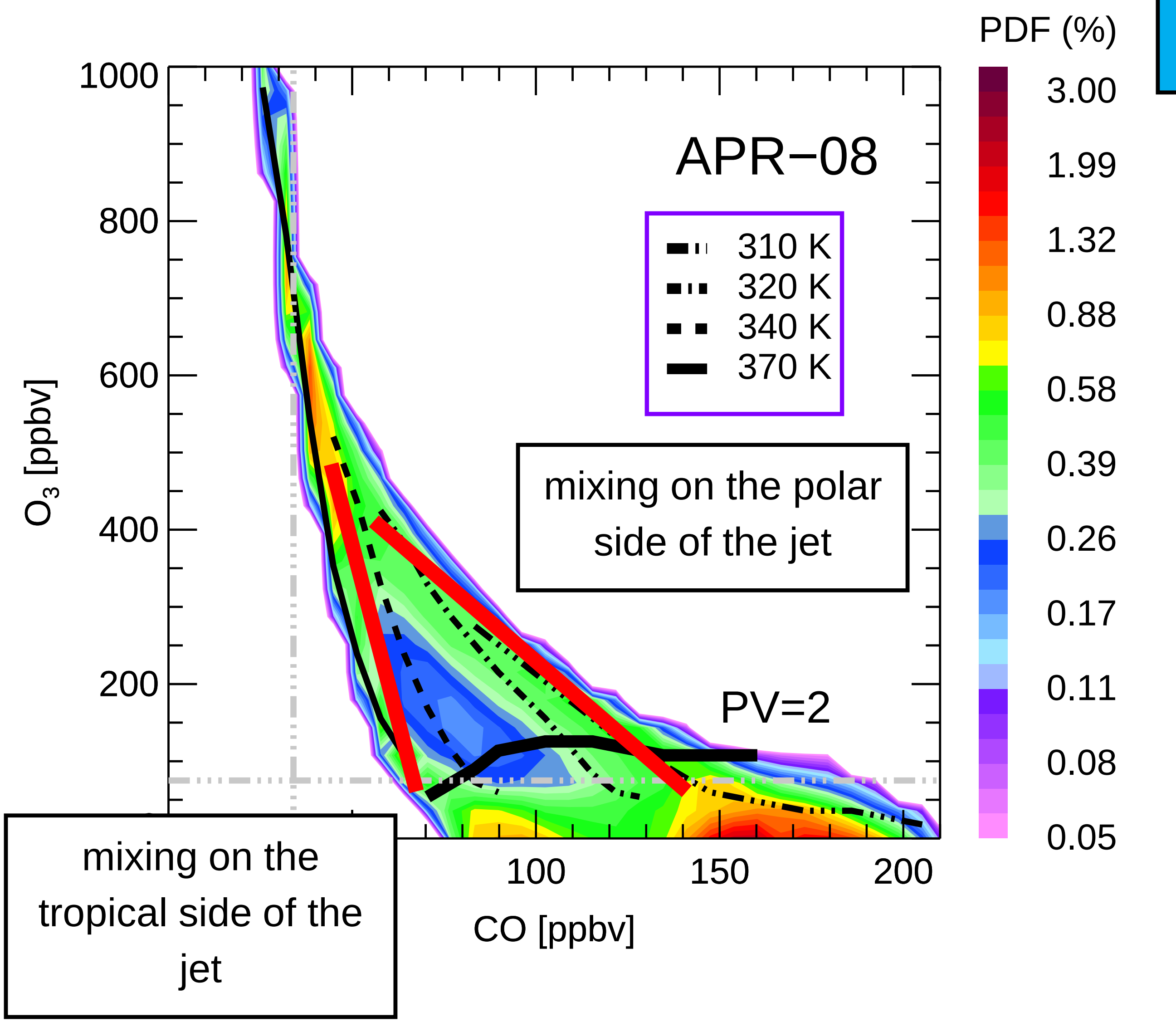
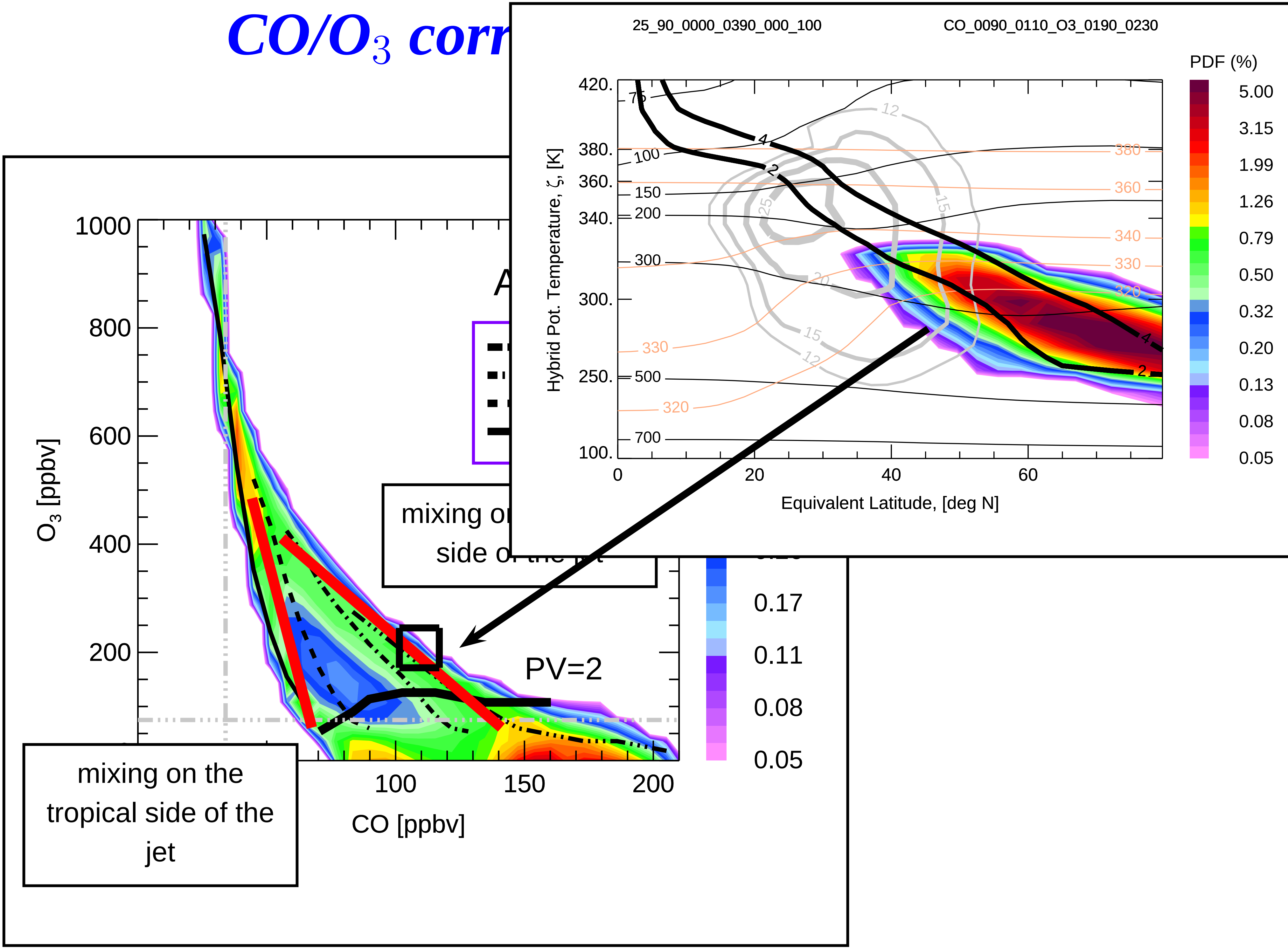


CO/O_3 corr


25_90_0000_0390_000_100
CO_0090_0110_O3_0190_0230
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0
20
40
60
Equivalent Latitude, [deg N]
75
100
150
200
300
500
700
380
360
340
330
320
330
320
12
15
25
20
15
12
4
2
4
2
1000
800
600
400
200
O_3 [ppbv]
100
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mixing o
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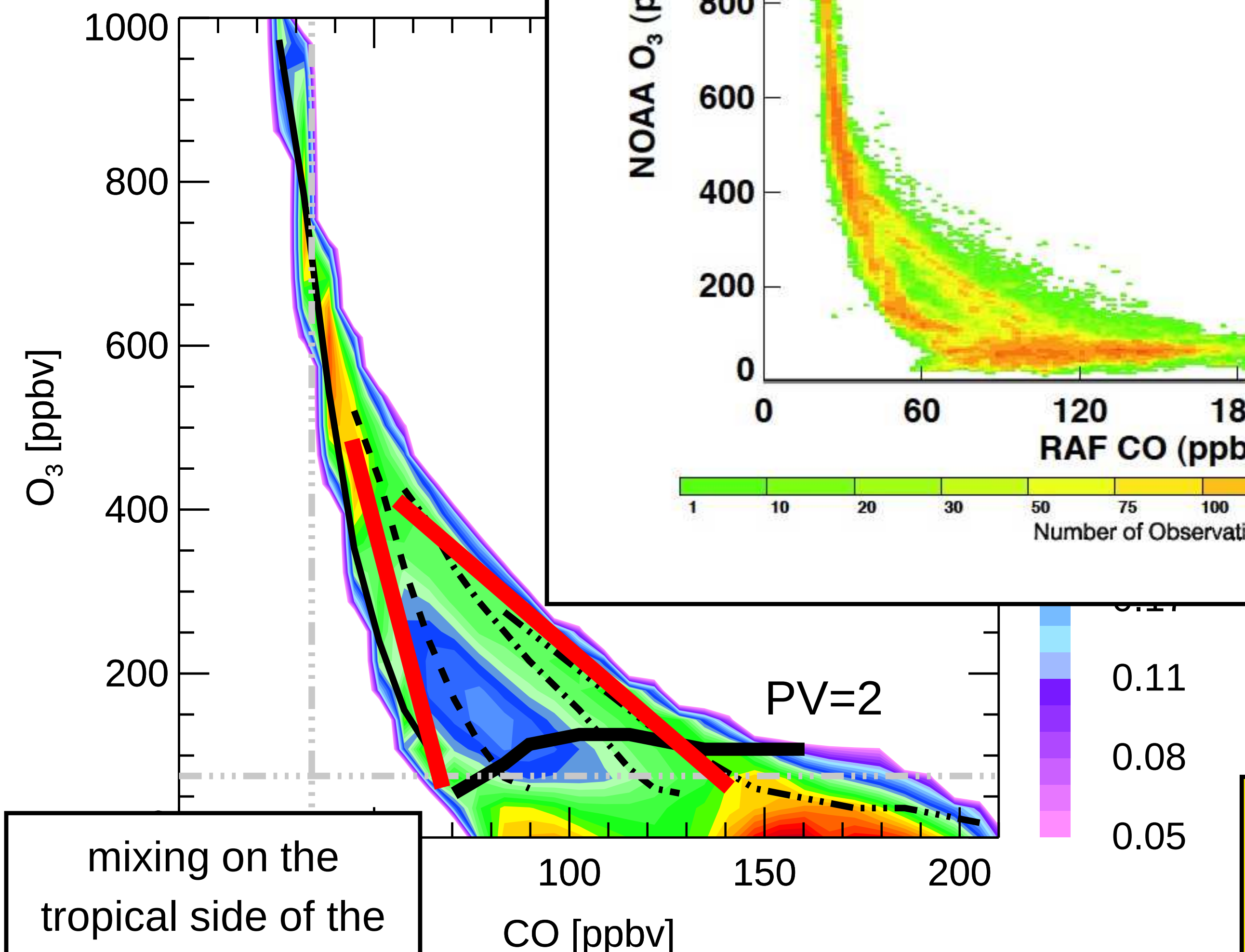
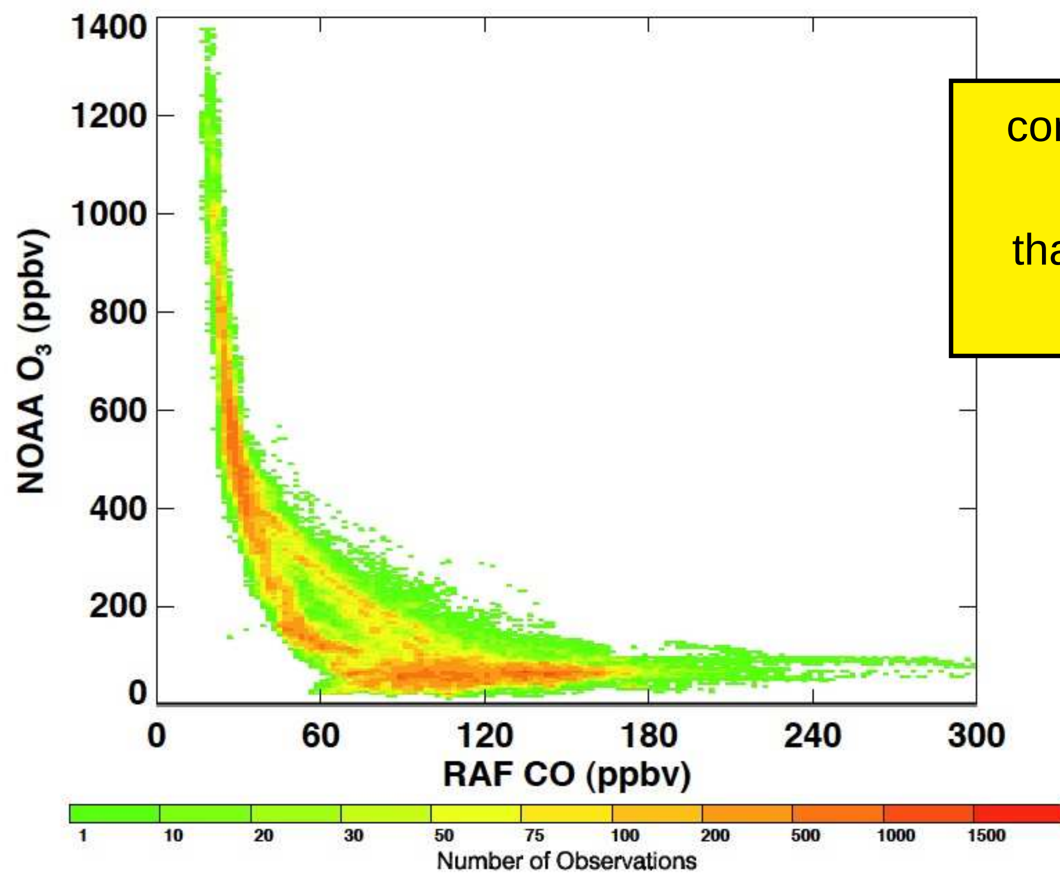
CO/O_3



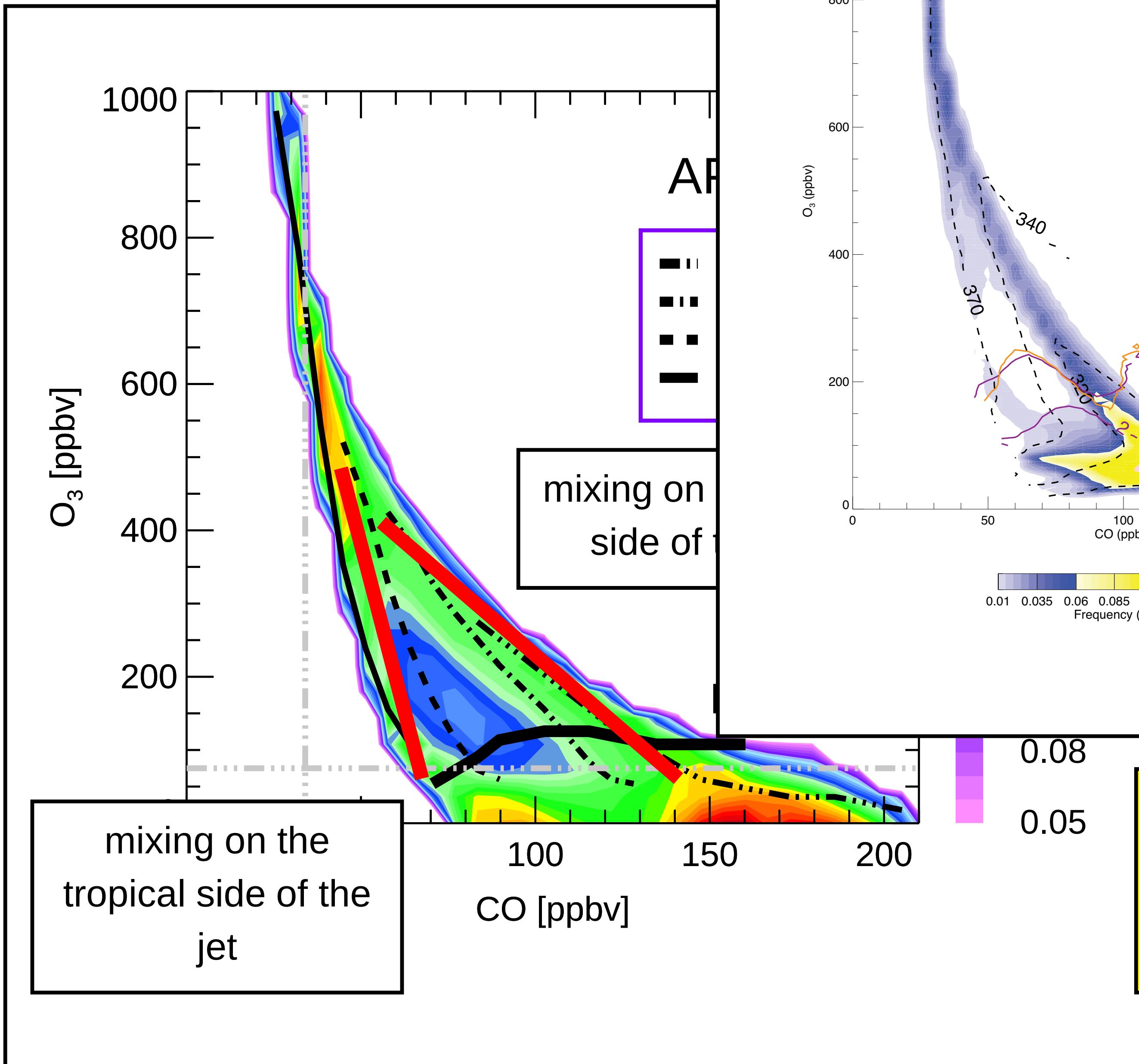


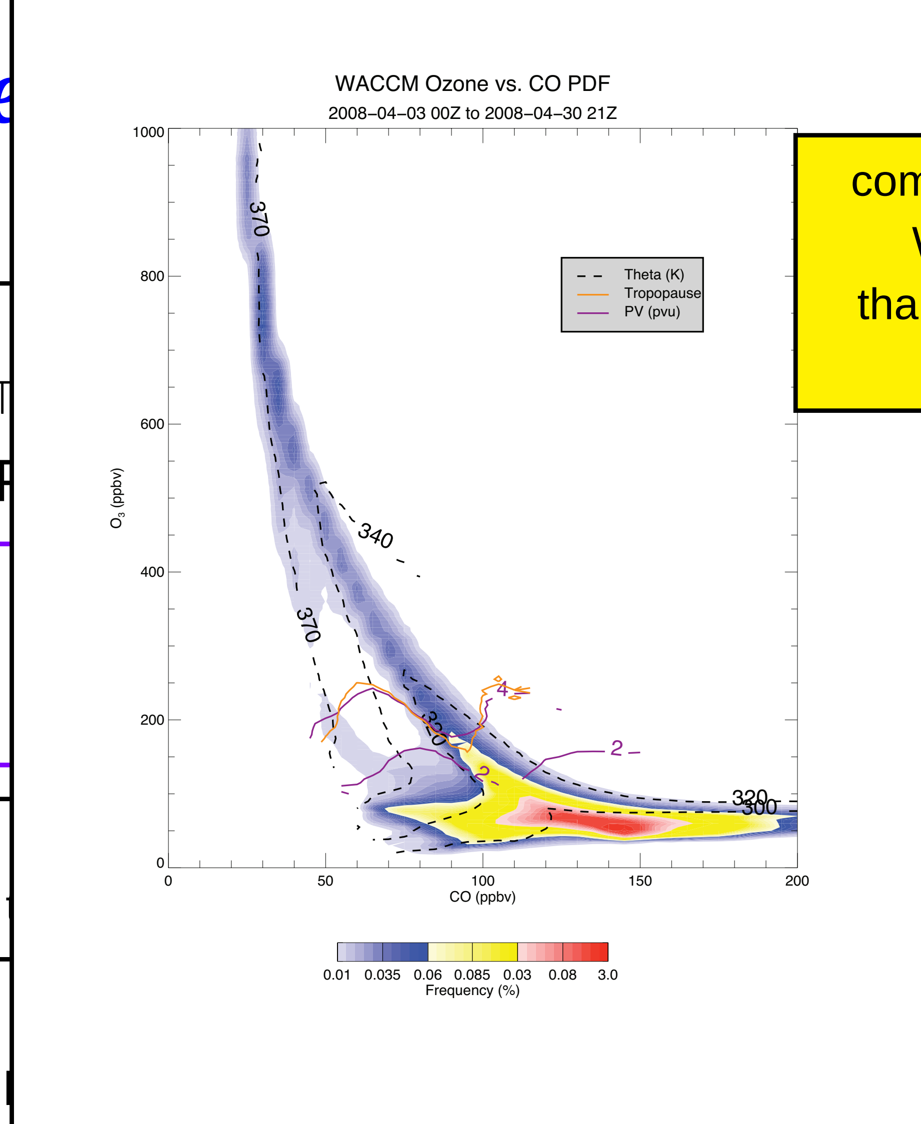
comparison with START-08 thanks to Jasna Pittman

mixing on the tropical side of the jet

Jet as a transport barrier in winter and spring e.g. Ray et al., JGR, 2004

CO/O_3 corre

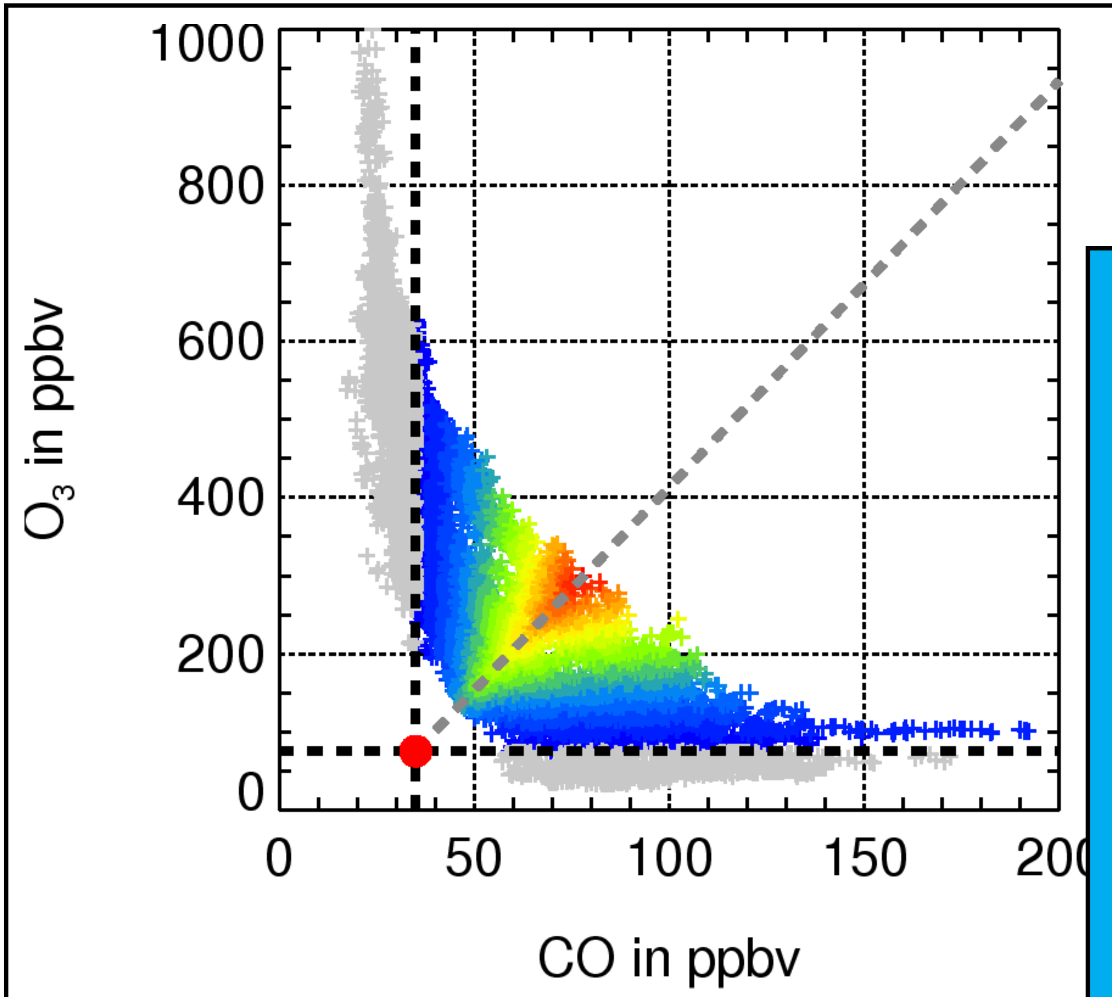




comparison with WACCAM thanks to Dalon Stone

Jet as a transport barrier in winter and spring
e.g. Ray et al., JGR, 2004

Degree of mixing derived from CO/O_3 correlation



from Kunz et al.
JGR, 2009

Empirical mixing state:

1. CO$<$35 ppbv - "pure" stratosphere
2. $O_3$$<$75 ppbv - "pure" troposphere
3. For other CO/O_3 values, we normalize CO and O_3, i.e.: x =CO/CO^{max} and y =$O_3/O_3{}^{max}$
4. Define (empirical mixing state):

$$f(x,y) = (x+y)\begin{cases} y/x & x > y \\ x/y & y > x \end{cases}$$

i.e. mixing is the highest along the diagonal and far away from the origin

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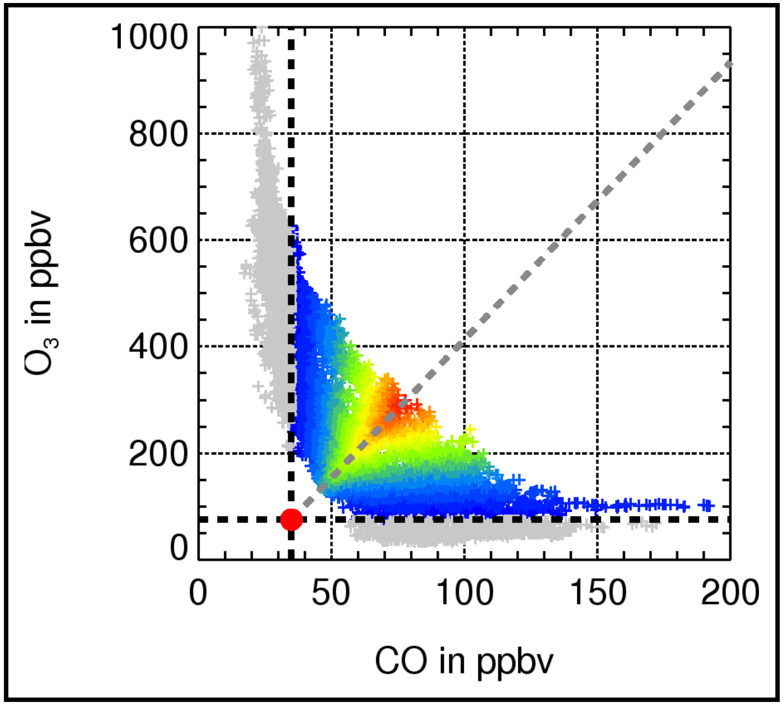

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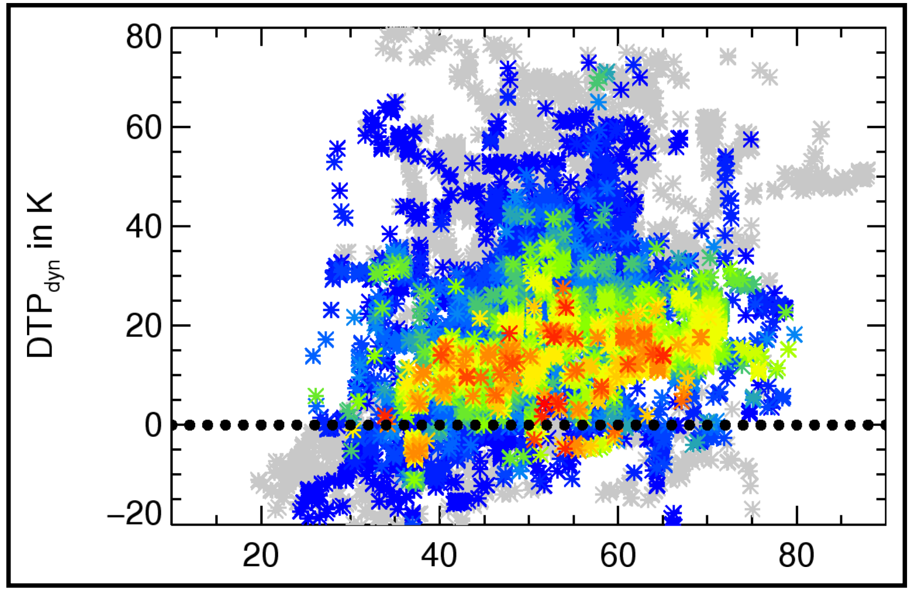

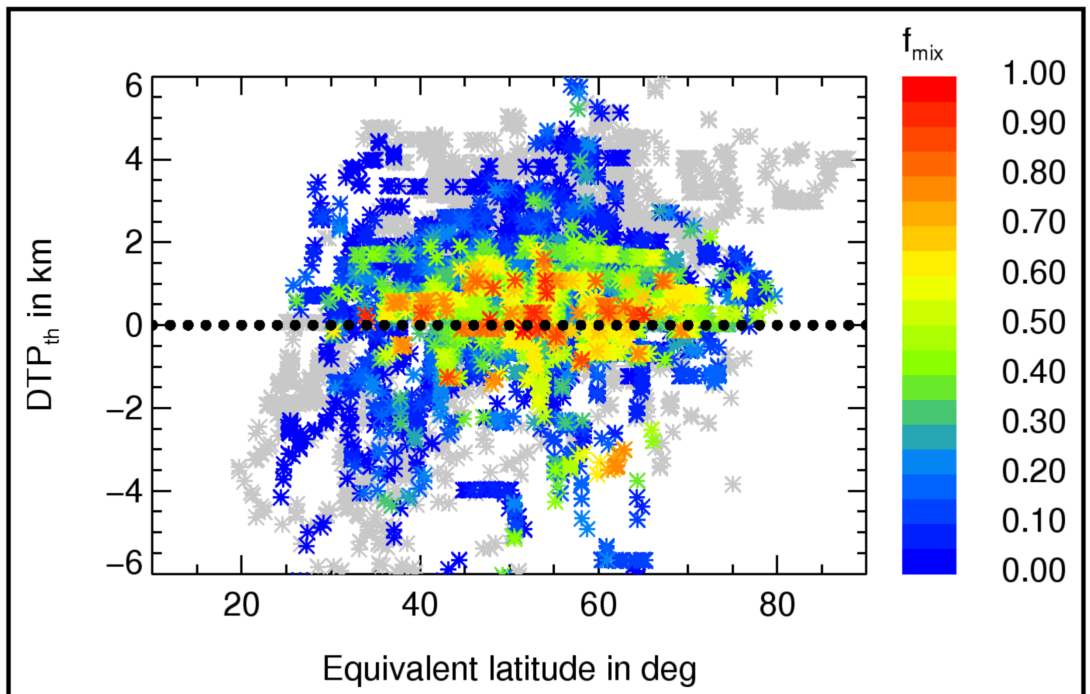

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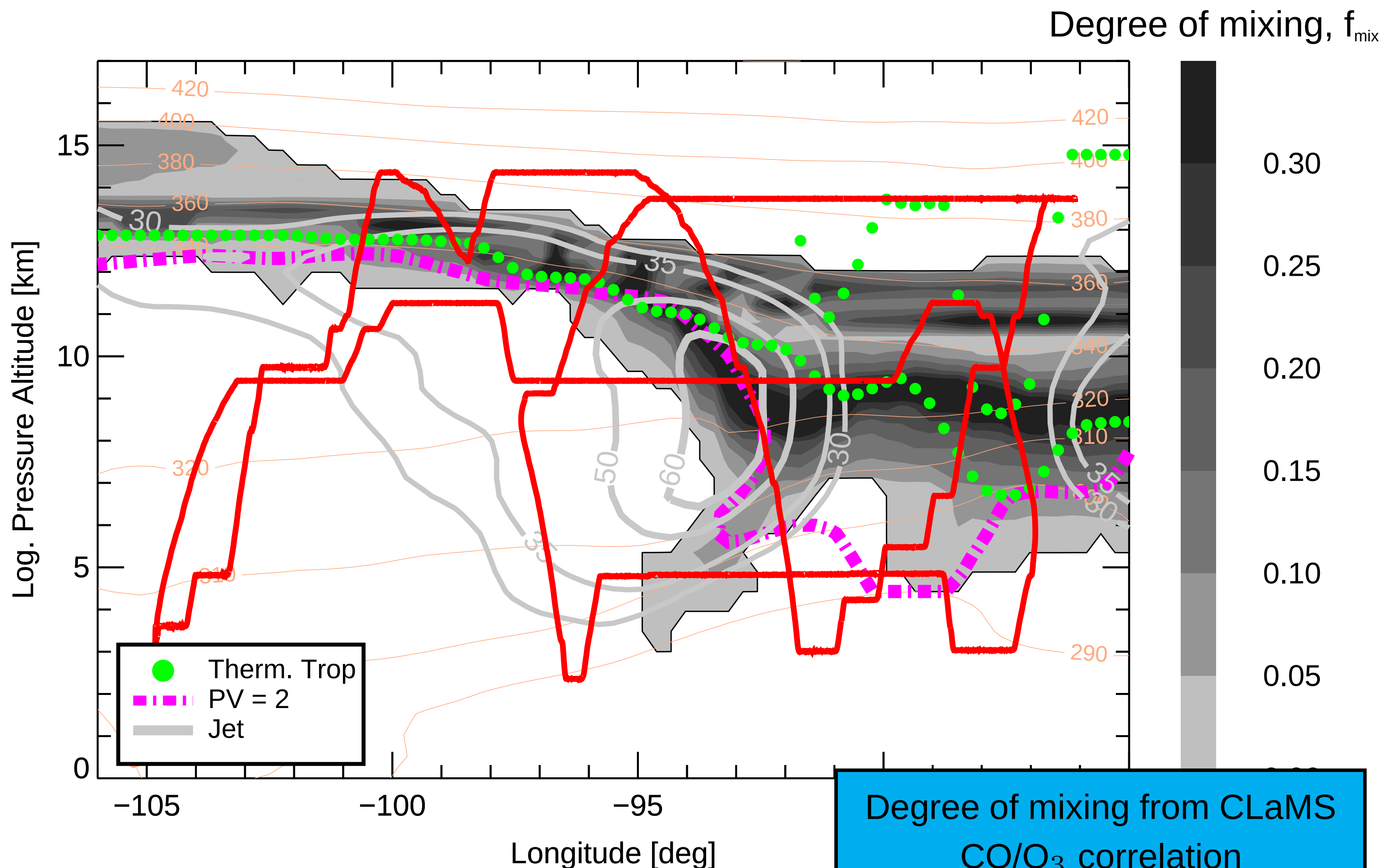
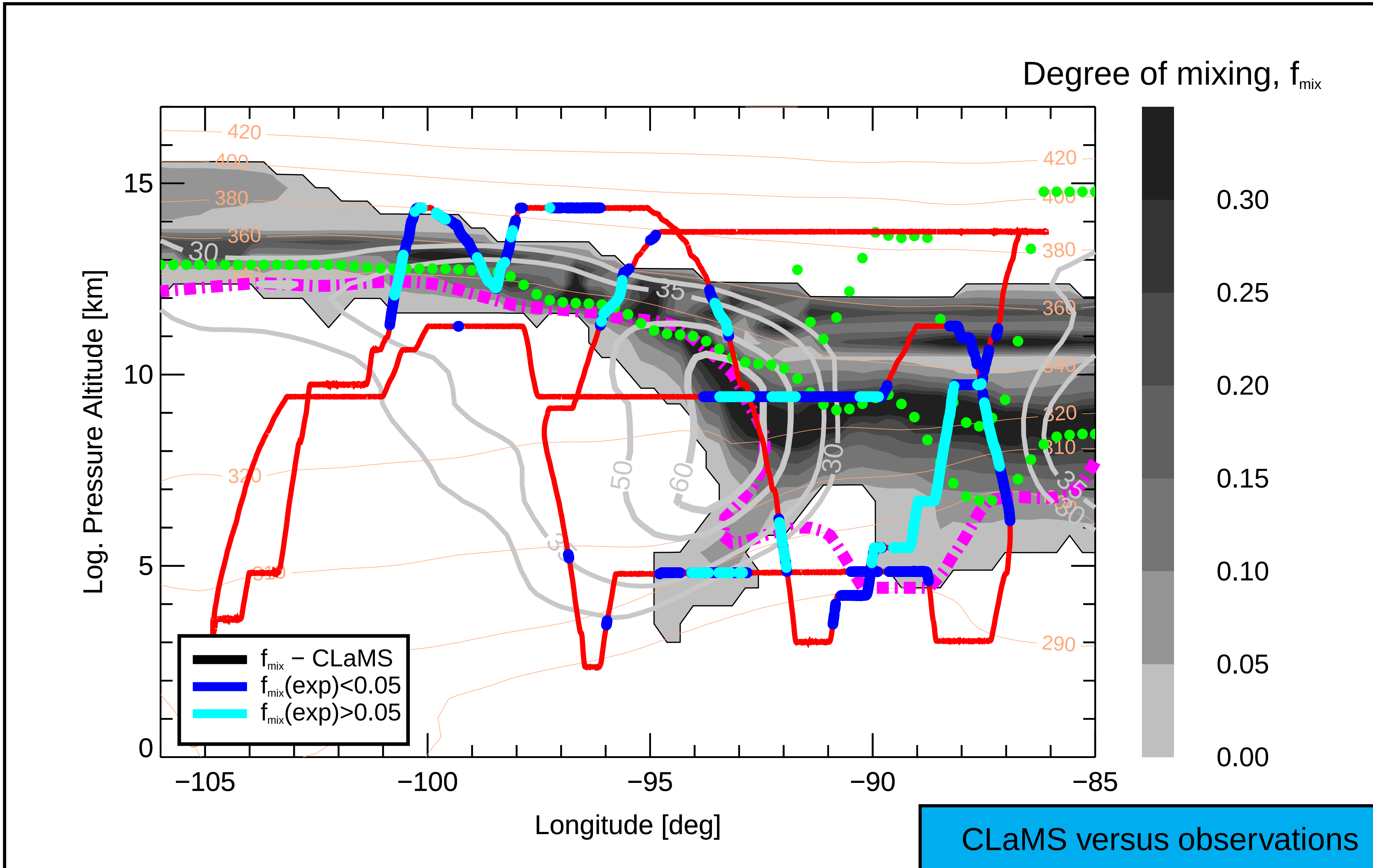
Mixing layer derived from CO/O_3 correlation



Degree of mixing from CLaMS
CO/O_3 correlation
stratospheric intrusion on 28.04
(see also Vogel et al.)

How good are our simulations ?



CLaMS versus observations stratospheric intrusion on 28.04 (see also Vogel et al.)

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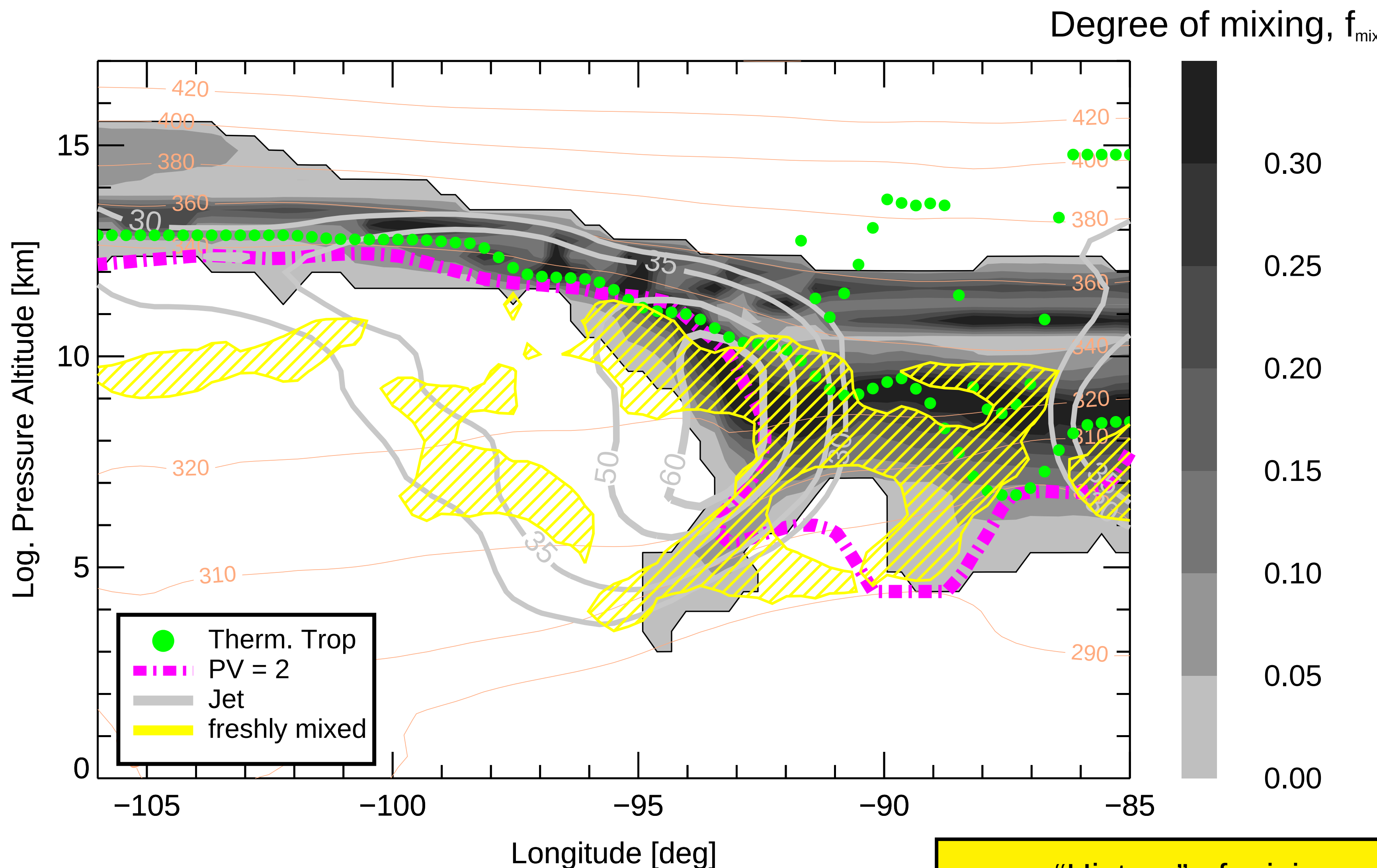

"History" of mixing:
yellow - mixing in CLaMS
occured in last 72 hours

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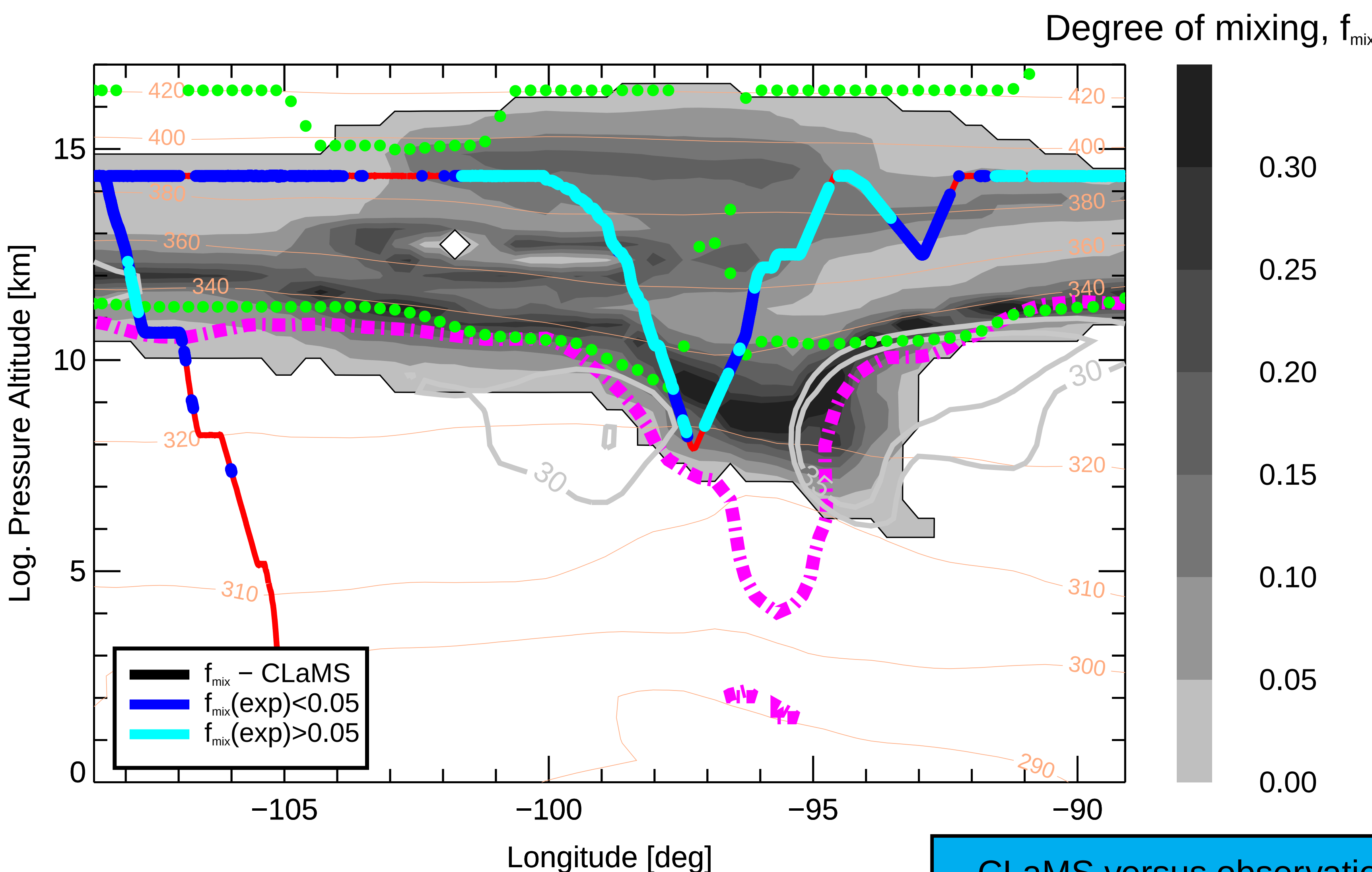
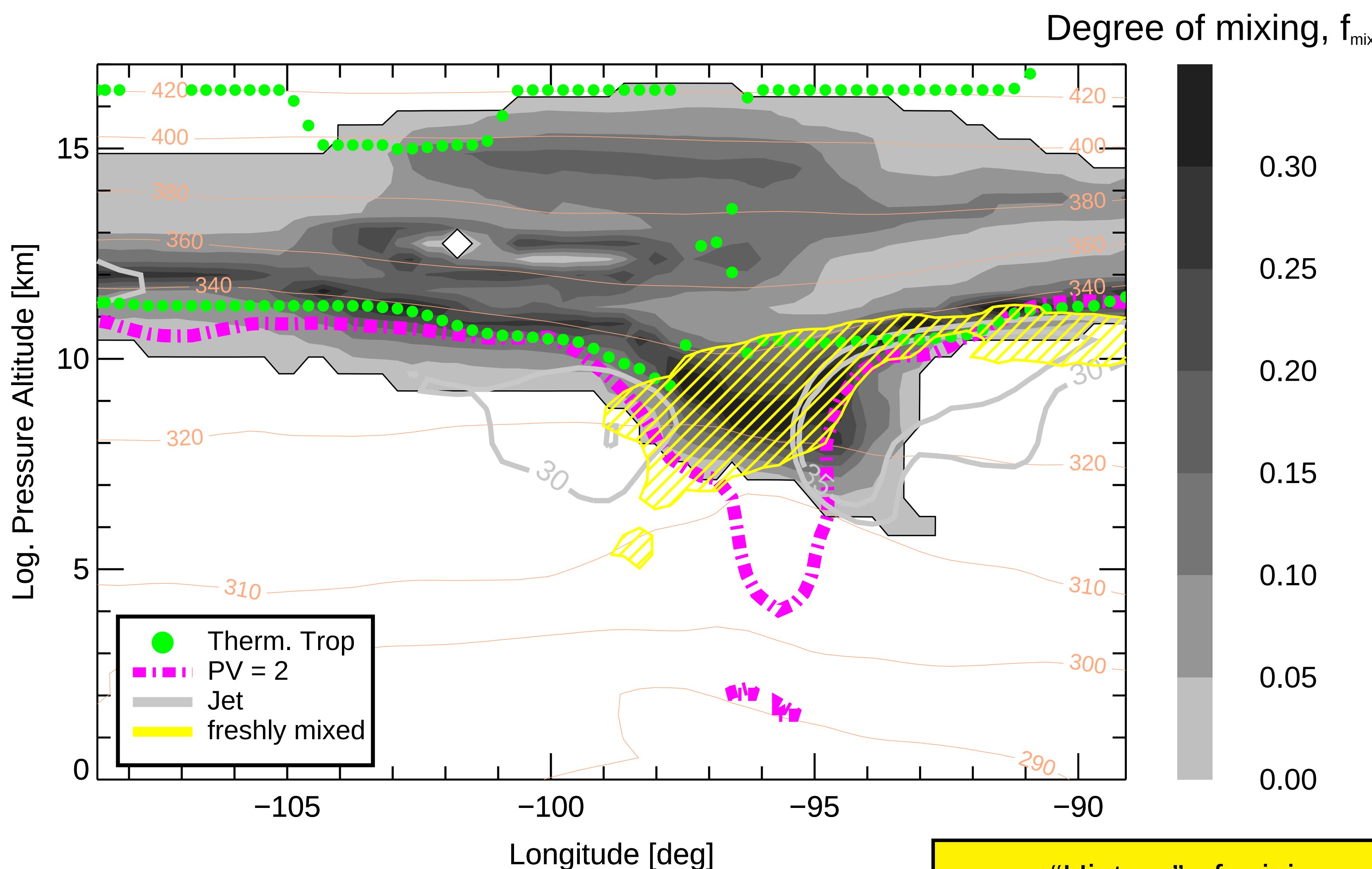


CLaMS versus observations
tropospheric intrusion on 18.04
(see also Vogel et al.)

How good are our simulations ?



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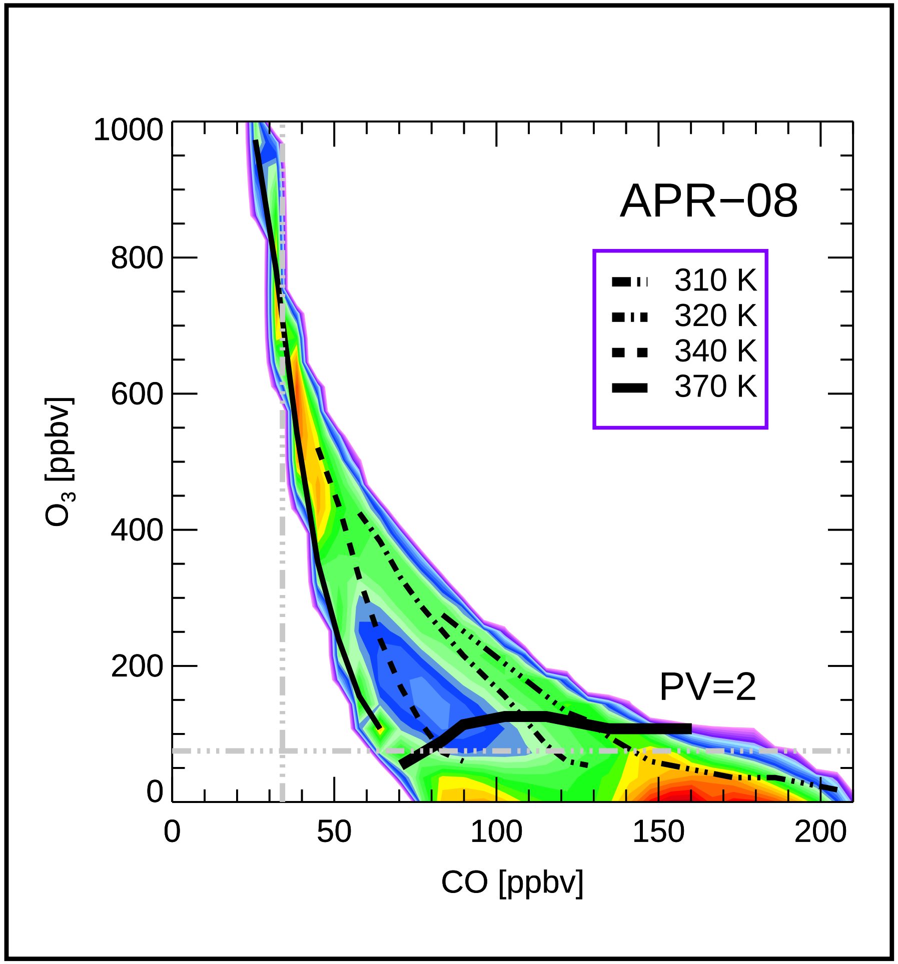
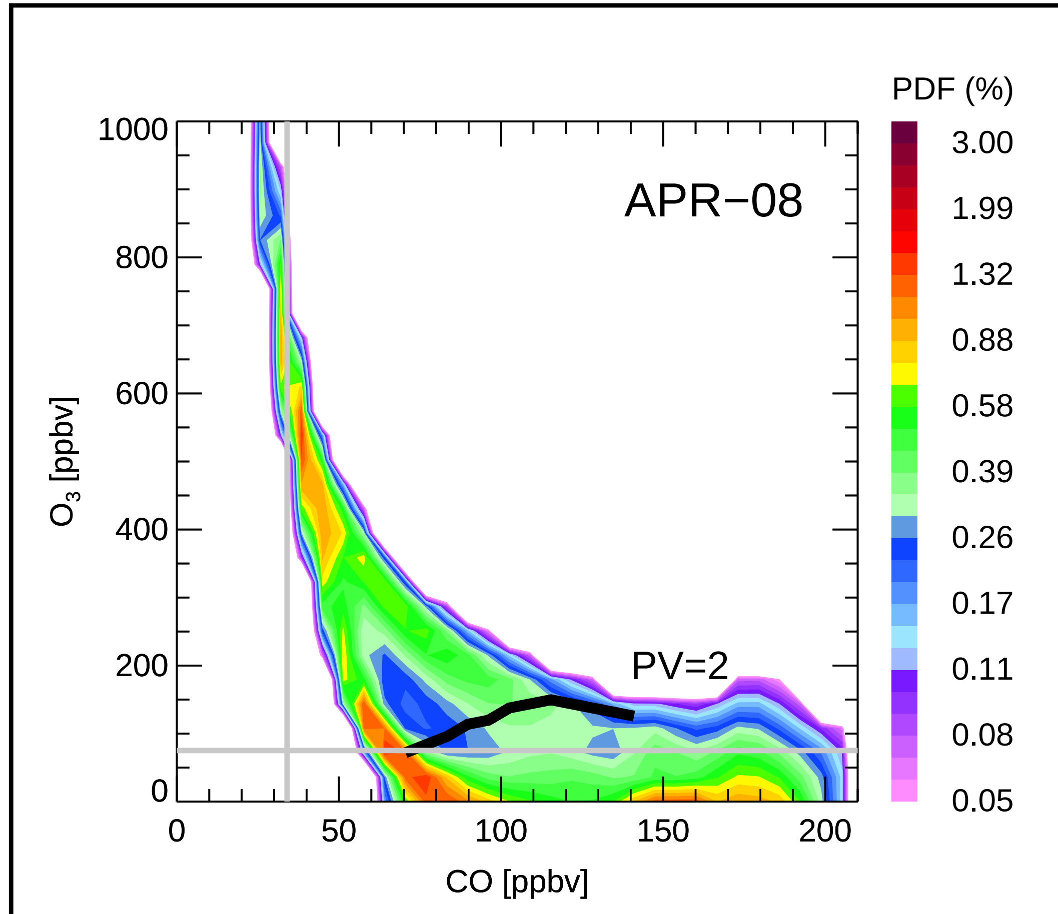
How sensitivity is the mixing layer in CLaMS ?



reference case



CLaMS with “reduced” intensity of mixing
⇒: not enough mixing in the troposphere
Mixing driven by the Richardson number:

$$Ri = \frac{\frac{g}{T}\frac{\partial \theta}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}, \quad Ri < Ri_c$$

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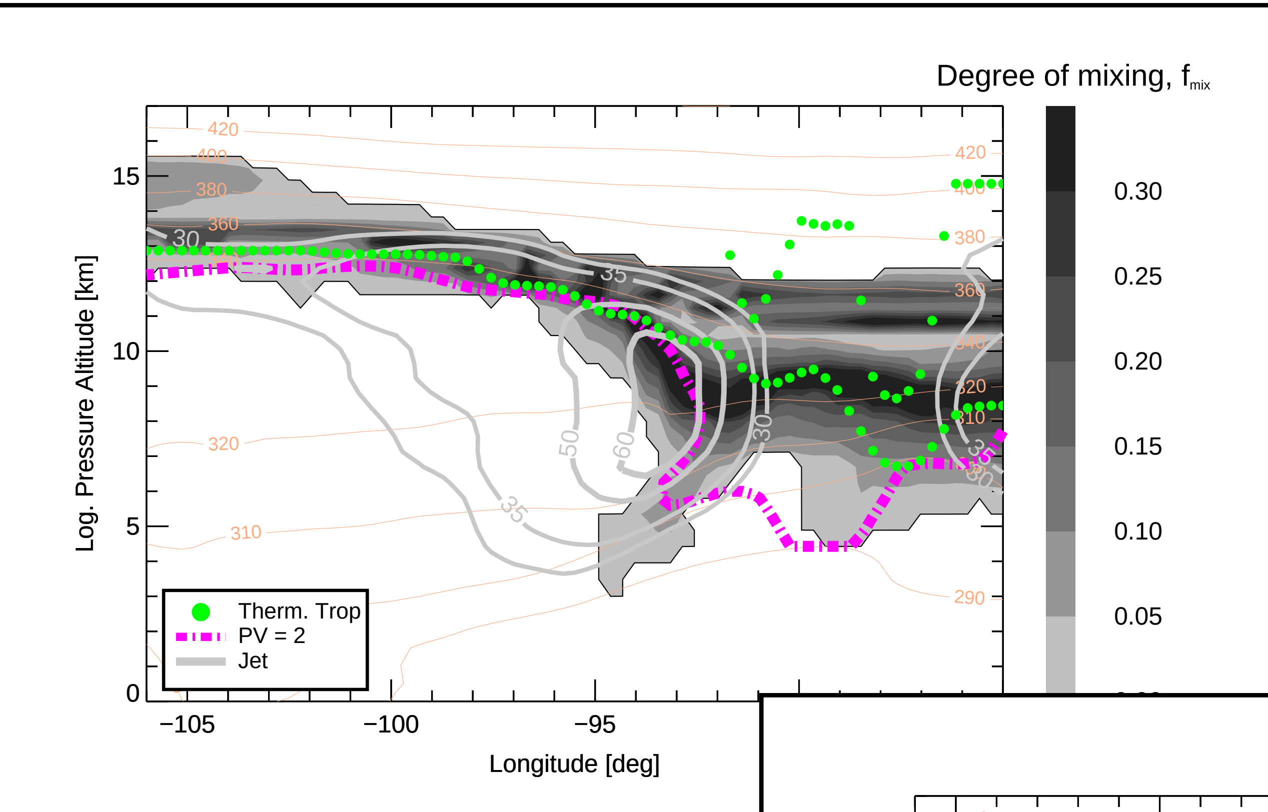
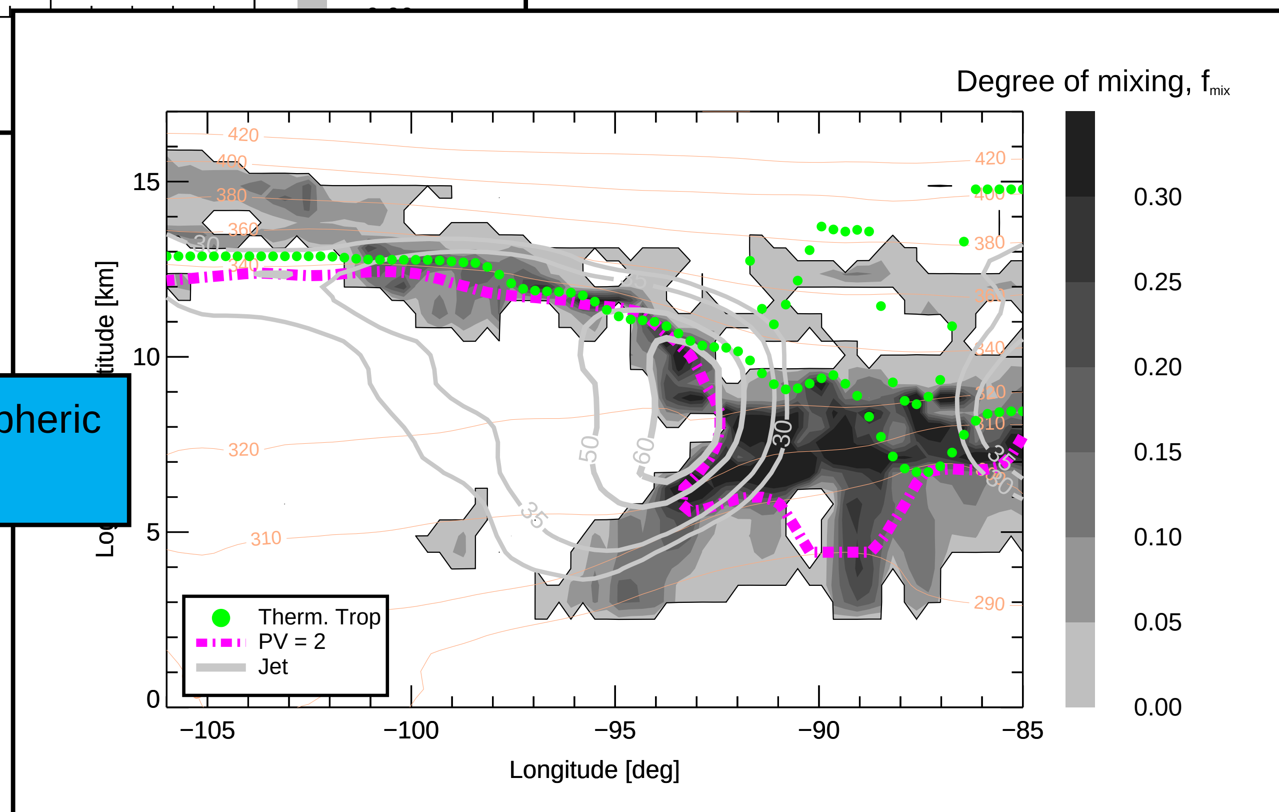
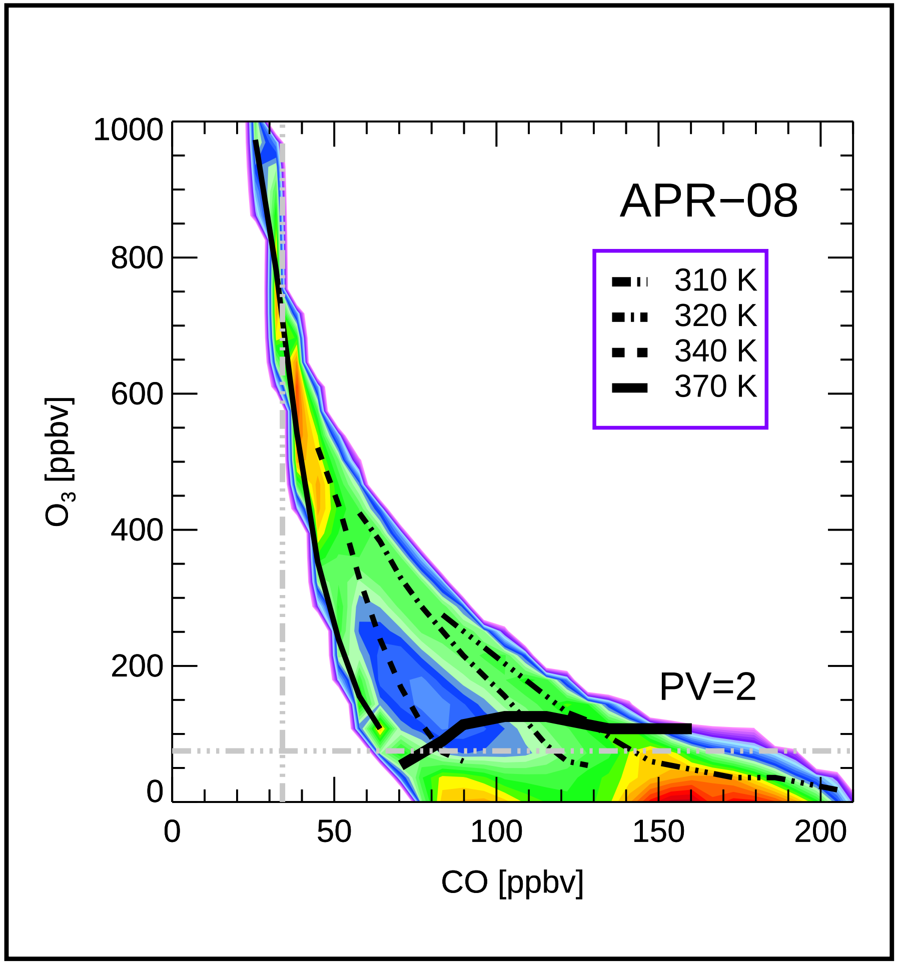
…ayer in CLaMS ?



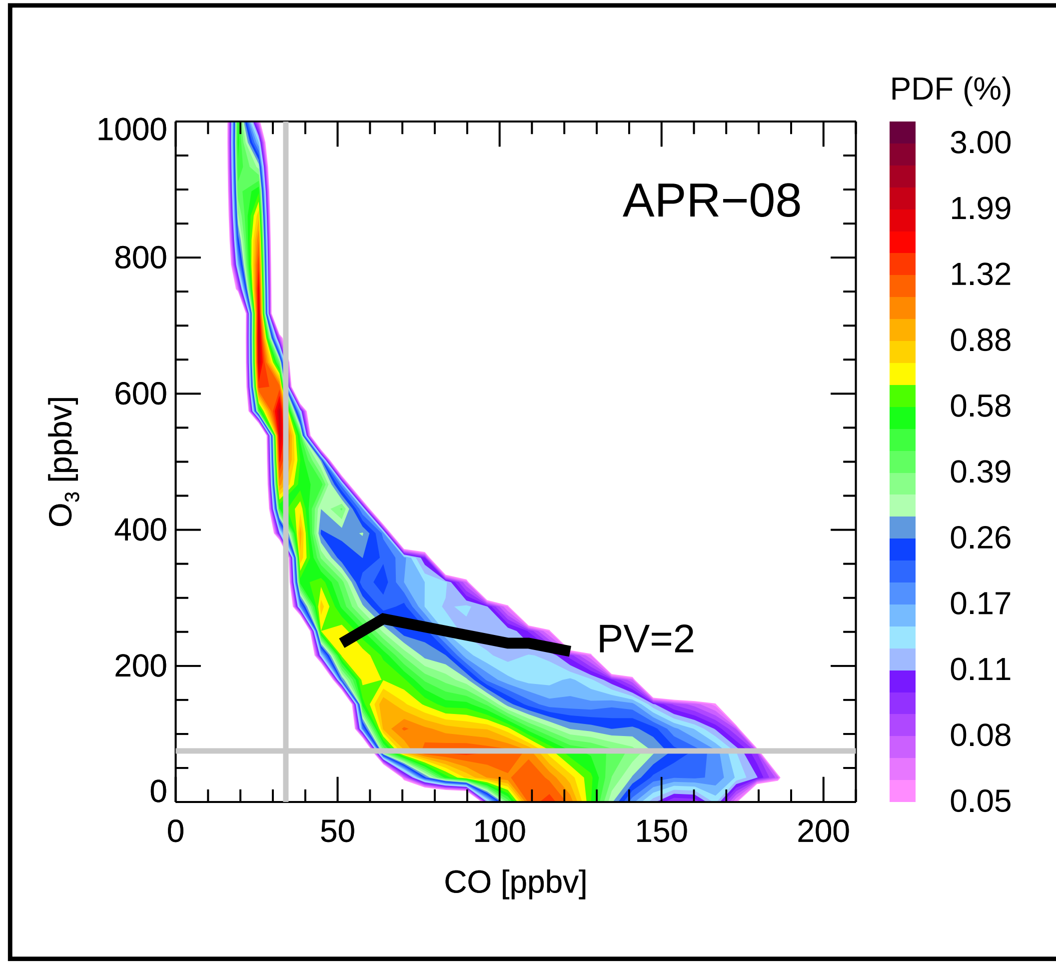


Reference (top) versus “too weak” tropospheric mixing (right)

How sensitivity is the mixing layer in CLaMS ?



reference case
(with annually averaged
mass conservation)



CLaMS with a “not balanced´´ Brewer-Dobson circulation
⇒: not enough upwelling in the tropics
⇒: “freedom” in the diabatic vertical velocities

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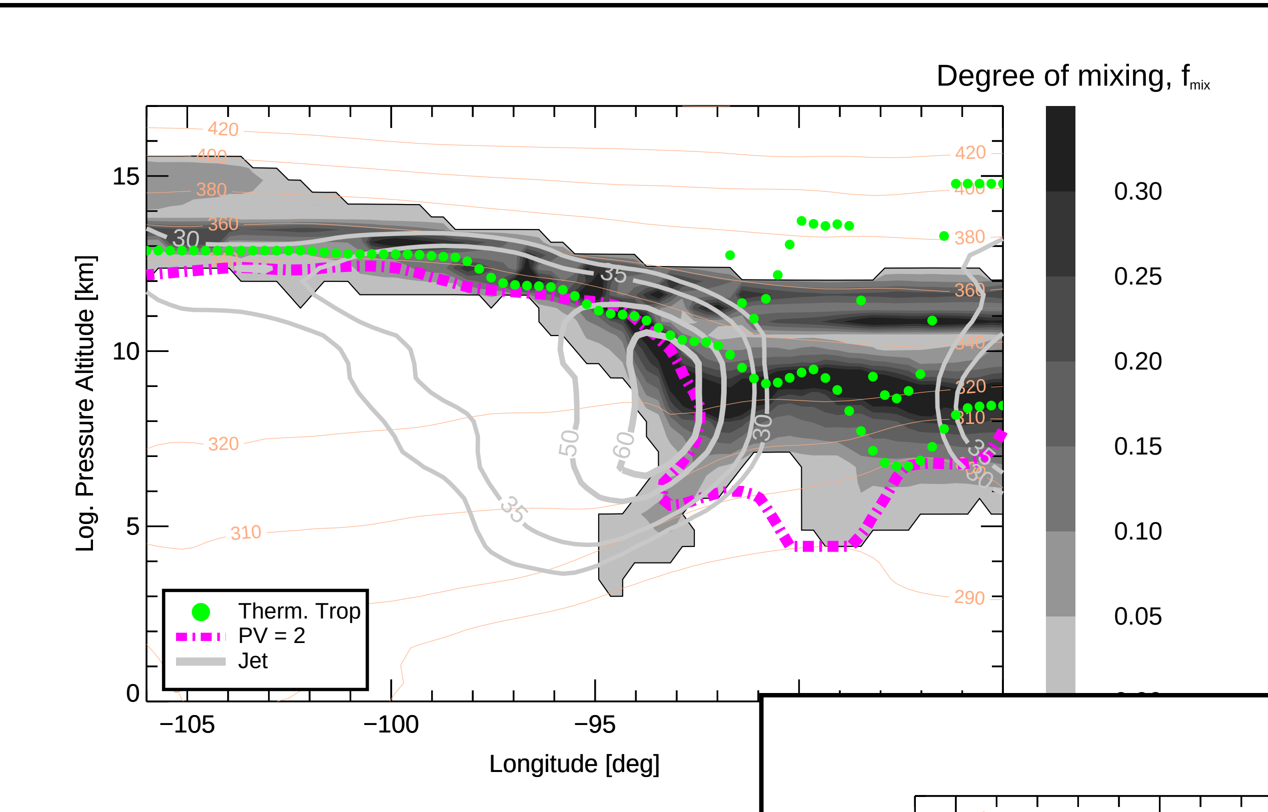
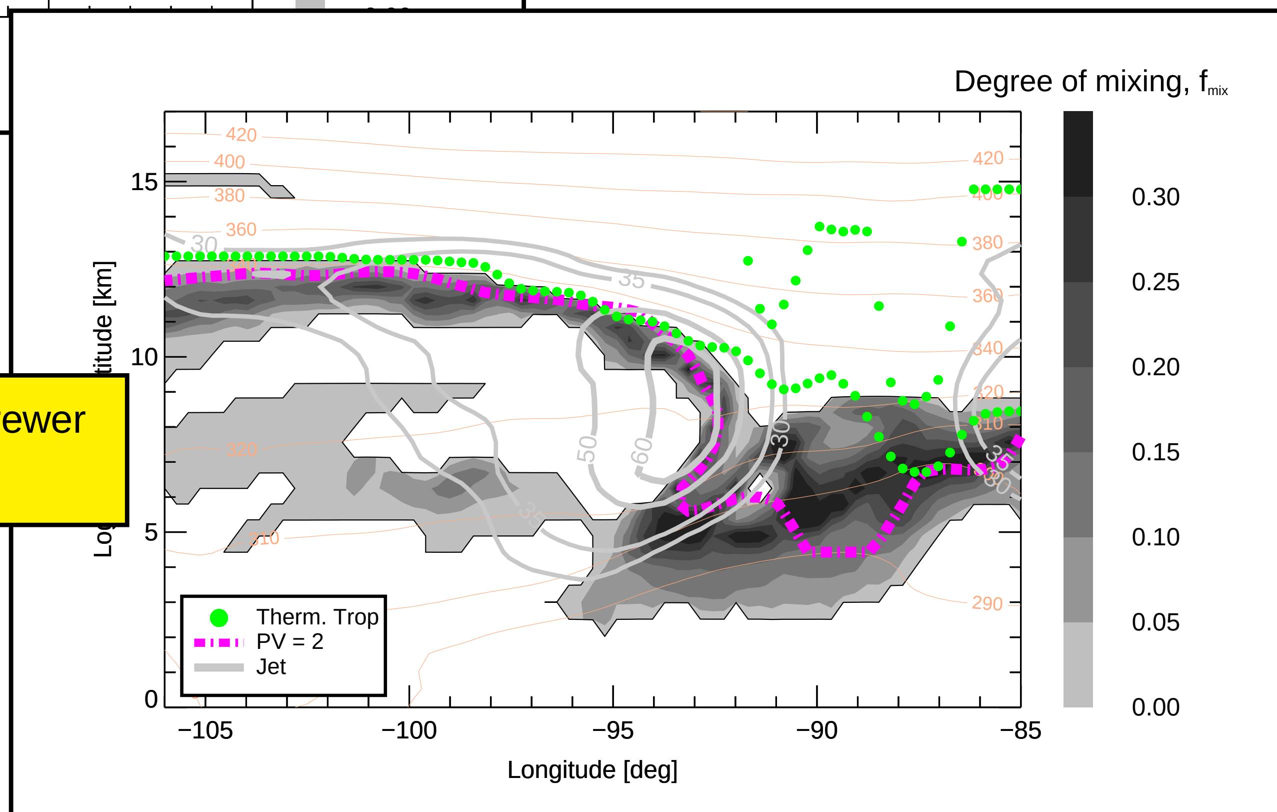
ayer in CLaMS ?





Reference (top) versus “not balanced” Brewer Dobson circulation (right)

Conclusions

- Degree of mixing can be diagnosed (experimentally and from a model) by using tracer correlations (here PDFs of CO/O_3) and an empirical function quantifying the position of air parcel in the tracer space f_{mix}.
- Position of the mixing layer (relative to the tropopause) strongly sensitive to the quality of the vertical velocities (Brewer-Dobson circulation)
  Generally: diabatic ($\dot{\theta}$) approach better than kinematic (Ω), see Plöger et al, JGR, 2009
- Thickness of the mixing layer sensitive to the mixing intensity in the model (CLaMS - still not enough mixing in the troposphere)
- "History" of mixing deduced from CLaMS:
  - "fresh" mixing (less than 72 hours) in the stratospheric intrusion on 28.04
  - "aged" mixing (more than 5 days) in the tropospheric intrusion on 18.04