Mixing in the vicinity of the subtropical and polar jets - Observations (START-05) versus CLaMS

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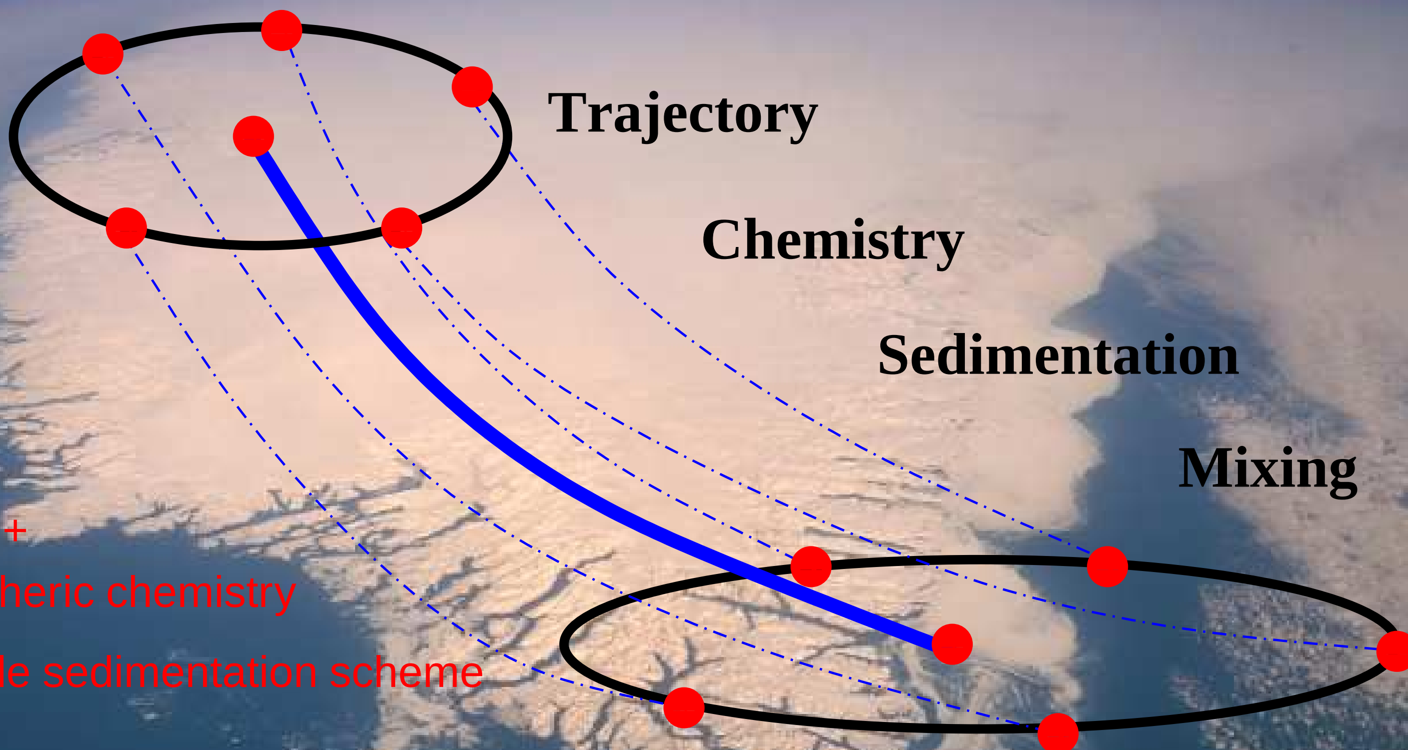
...CLaMS-Model...

CLaMS-Model

- CLaMS - Lagrangian Chemistry Transport Model
- Potential temperature/pressure as vertical coordinate in the stratosphere/troposphere
- Horizontal and vertical velocities from meteor. winds (ECMWF) and/or a radiation scheme
- Lagrangian mixing



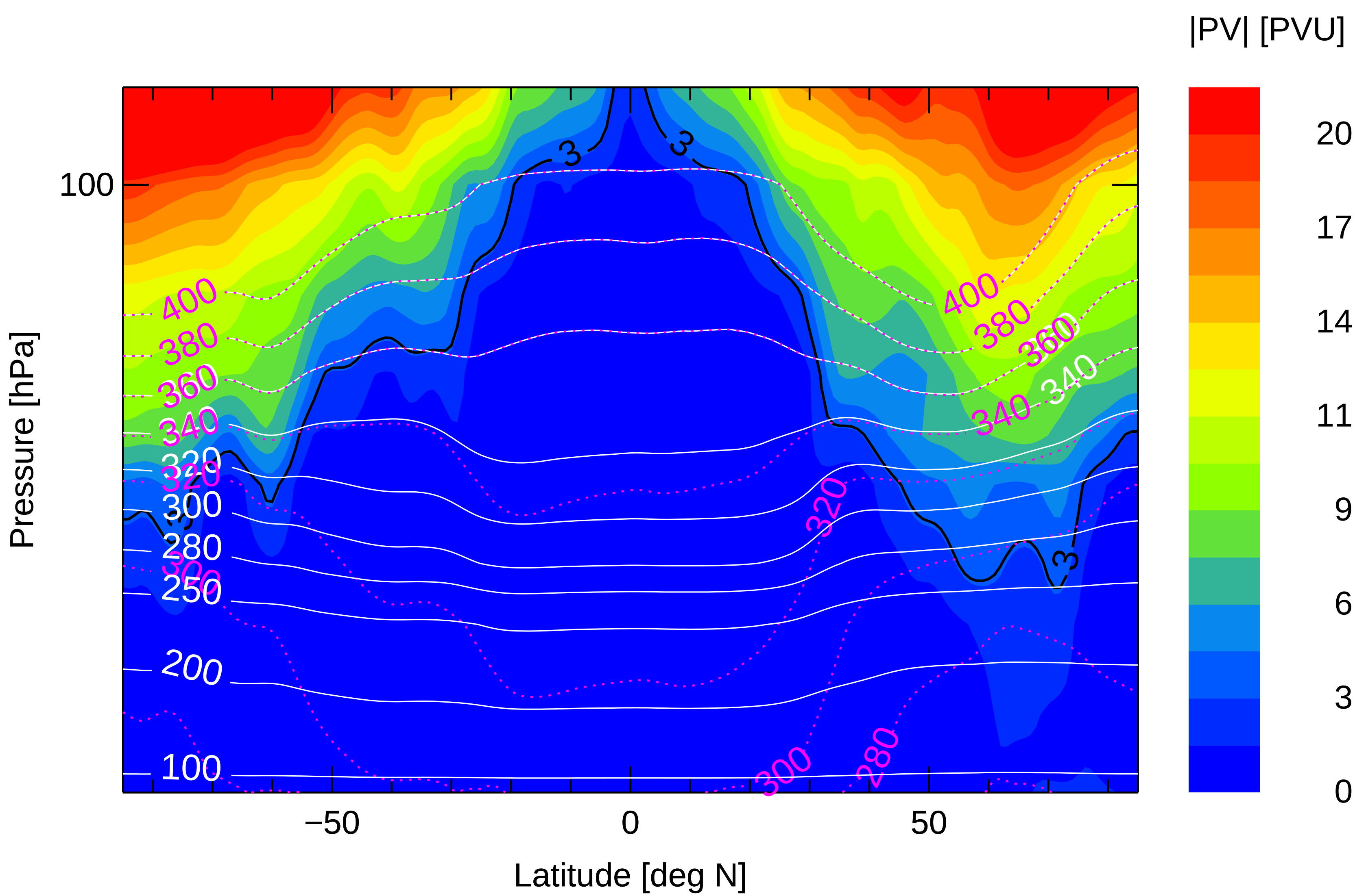
- Full stratospheric +
  simplified tropospheric chemistry
- Lagrangian particle sedimentation scheme
- parallelized code

McKenna et al., JGR, 2002, Konopka et al., JGR, 2004, Grooß et al., 2005, ACP,
Konopka et al., ACP, 2007

Greenland from space shuttle (NASA)

CLaMS with stratosphere and troposphere

Convection AND radiative forcing ⇒ Hybride ζ-coordinates, Mahowald et al., JGR, 2002



Vertical cross section of PV (ECMWF), Konopka et al., ACP, 2007

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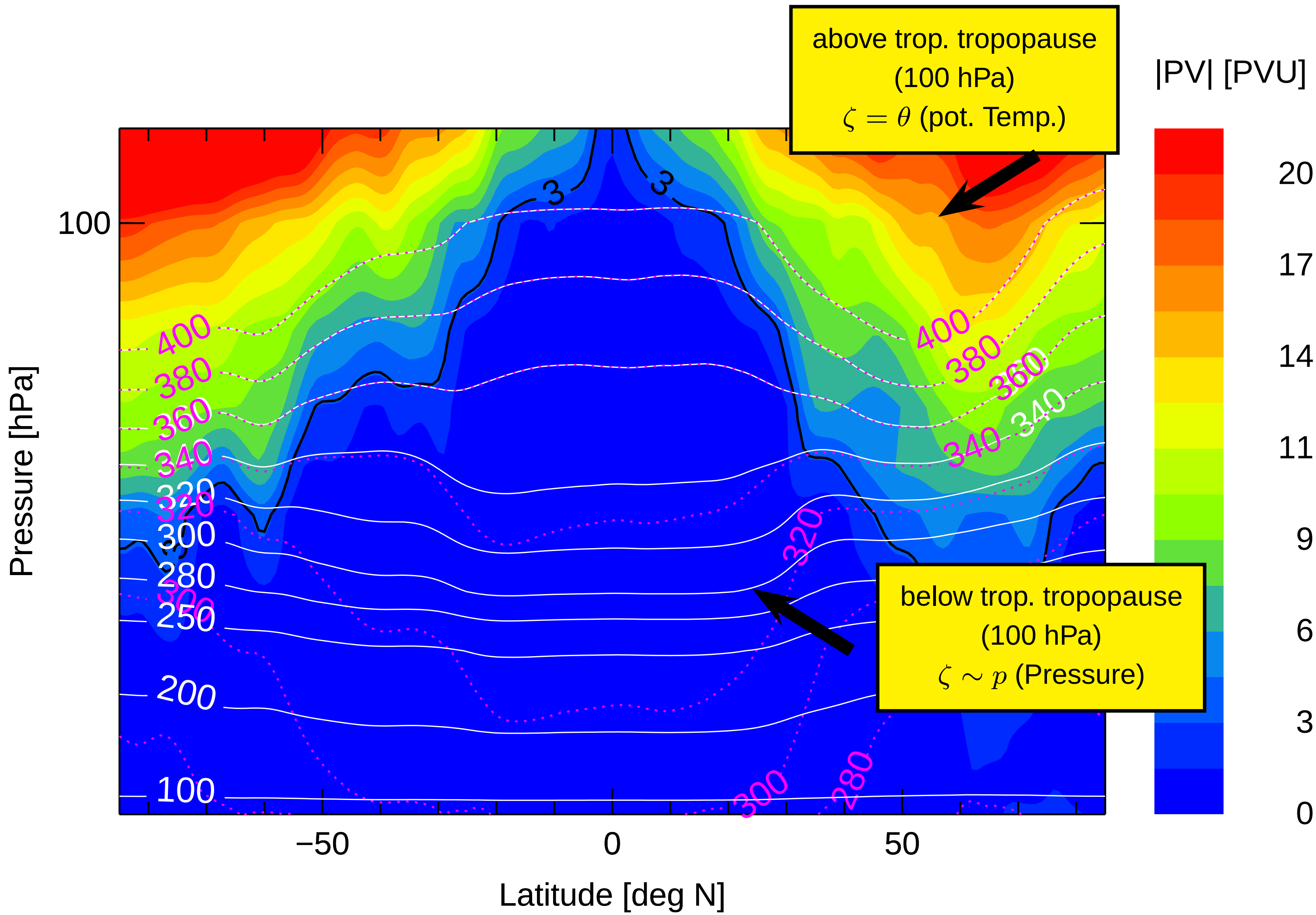

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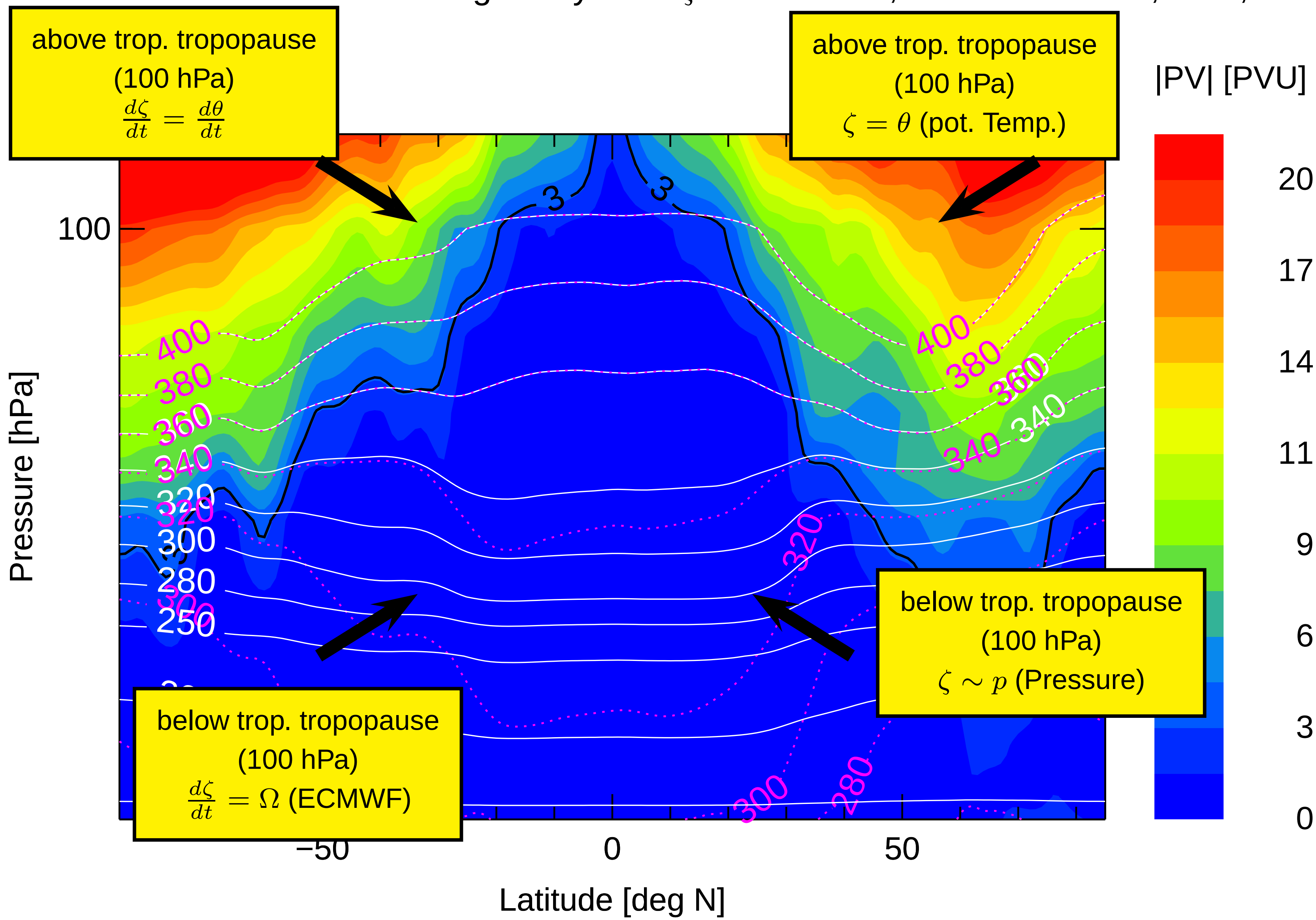

Vertical cross section of PV (ECMWF), Konopka et al., ACP, 2007

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Multi-annual CLaMS simulations

- Model domain: Troposphere+Stratosphere

  lower boundary: $50 \leq \zeta \leq 100$K + orography following layer with $\Delta\zeta = 50$K

  upper boundary: $\theta = 2500$ K (stratopause), Konopka et al., ACP, 2007

- Considered species

species	lower boundary	upper boundary
CH_4	CMDL	HALOE
Mean Age	linear source	MIPAS (SF6)
CO_2	CMDL	CMDL+Mean Age
CO	CMDL+MOPITT	Mainz-2D
O_3	0	HALOE, $\theta \geq 500$ K
O_3 (tracer)	0	HALOE, $\theta \geq 500$ K
HCl	0	HALOE, $\theta \geq 500$ K
H_20	ECMWF, $\theta \leq 380$ K, ($\zeta = 280$ K)	HALOE
N_2O, F11	CMDL (CATS)	0

- HALOE - Climatology:
Grooss and Russell, ACP, 2005
- CMDL: GLOBALVIEW, 2007
CO_2/CH_4/CO since 1979/84/91
P. Tans, K. Masarie, P. Novelli
- CMDL: CATS (4 stations)
N_2O, F11, J. Elkins
- MIPAS, SF6-Age
Stiller et al., ACPD, 2007
- MOPITT (V3)
Walter at al., PhD, 2008

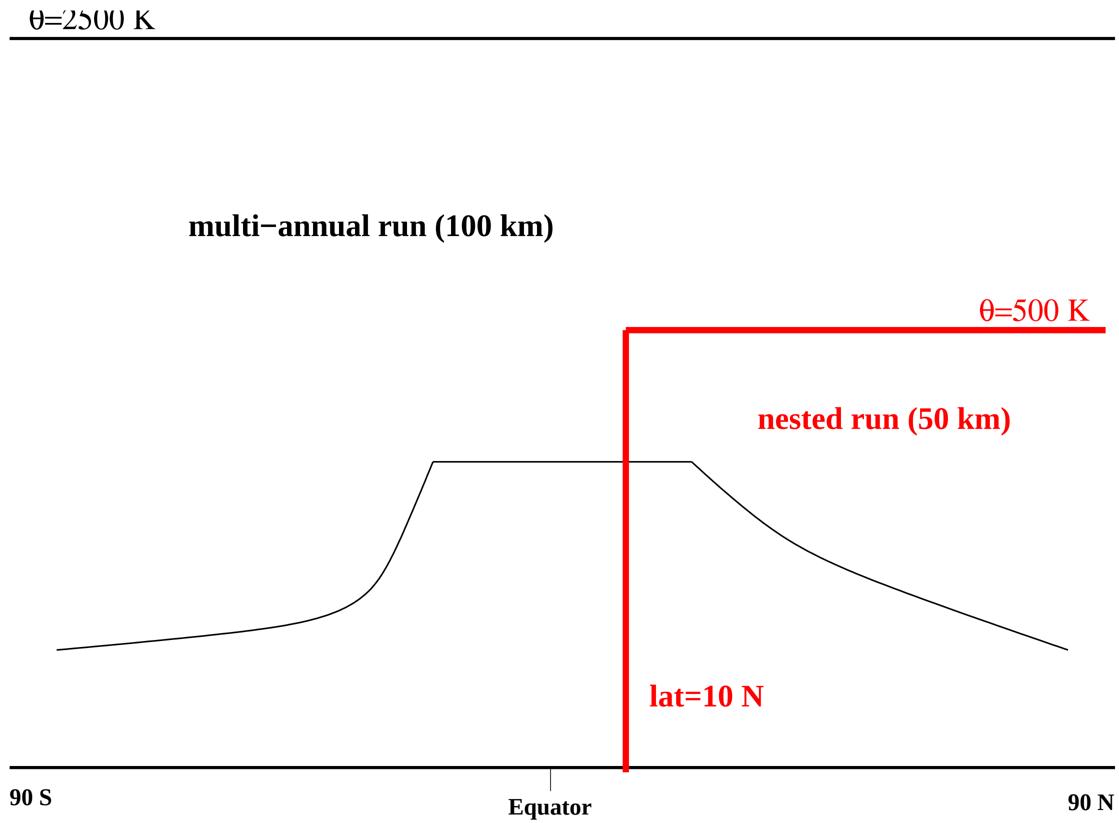
- Simplified chemistry

$$CH_4 \Rightarrow (OH, O(^1D), Cl) \Rightarrow H_2O, CO \Rightarrow (OH) \Rightarrow CO_2$$

$$(h\nu) \Rightarrow O_3$$

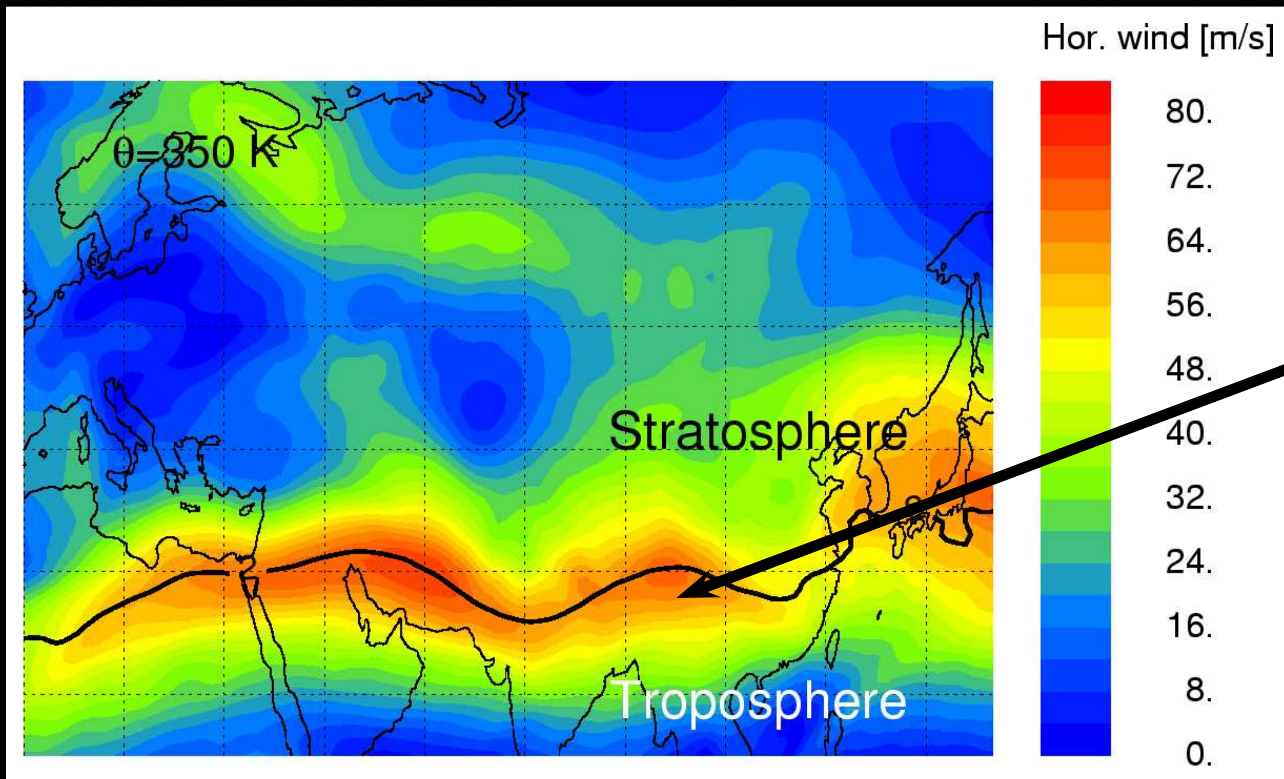
$$N_2O, F11 \Rightarrow (O(^1D), h\nu)$$

- Multi-annual: 1.10.2001 - 1.09.2006 (today)
- Entropy preserving layer, highest vertical resolution with $\alpha = 250$ around $\theta = 380$ K
- Perpetuum runs ($\approx$ 5 years) to find a stationary state (initial condition from HALOE or Mainz-2D). Such a stationary state is used as the initial distribution for the main run.
- Hor. resolution: 200/100 km + nested runs (50 km)



...Mixing in CLaMS...

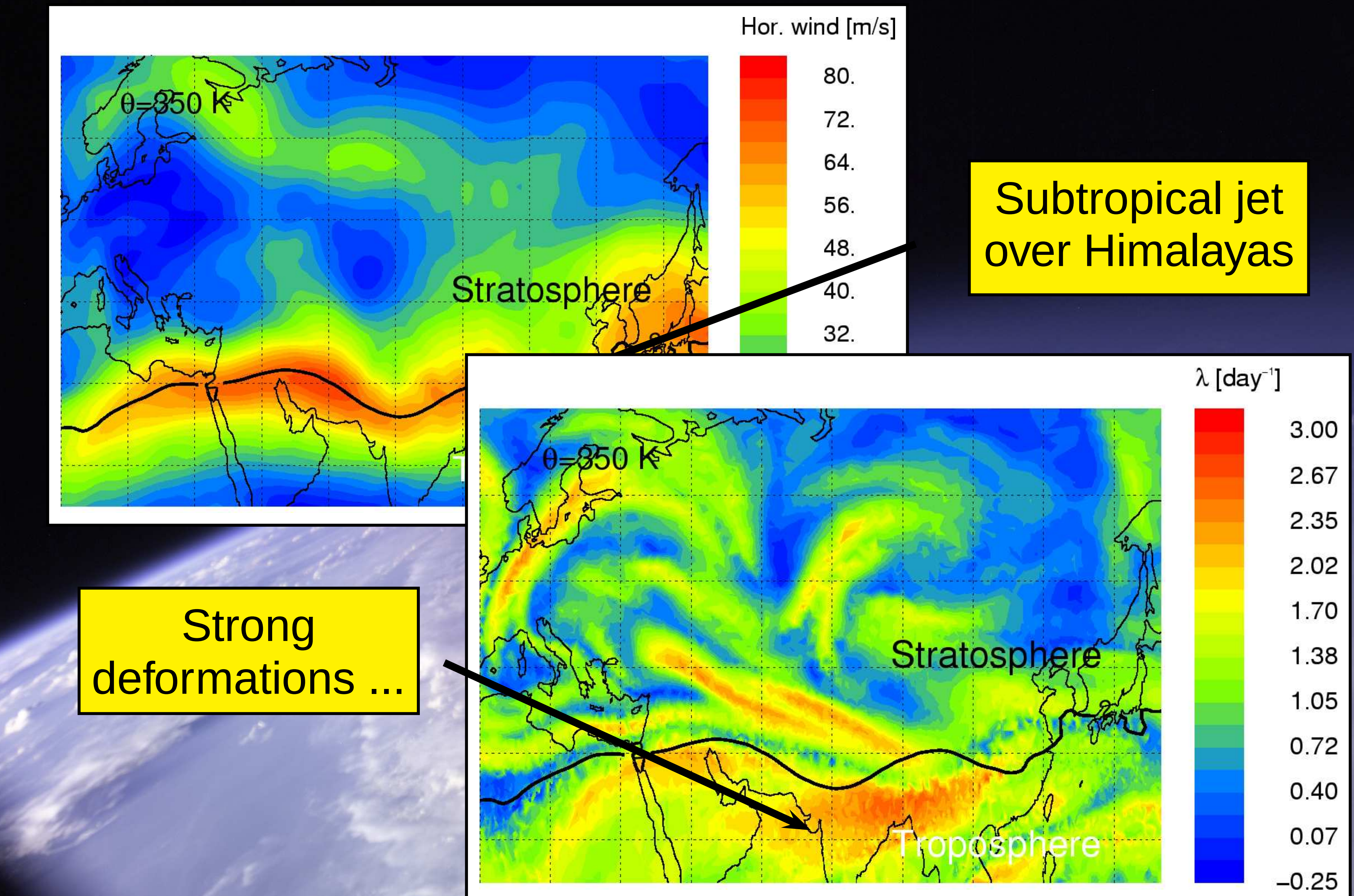
Mixing in the vicinity of the subtropical jet



Subtropical jet over Himalayas

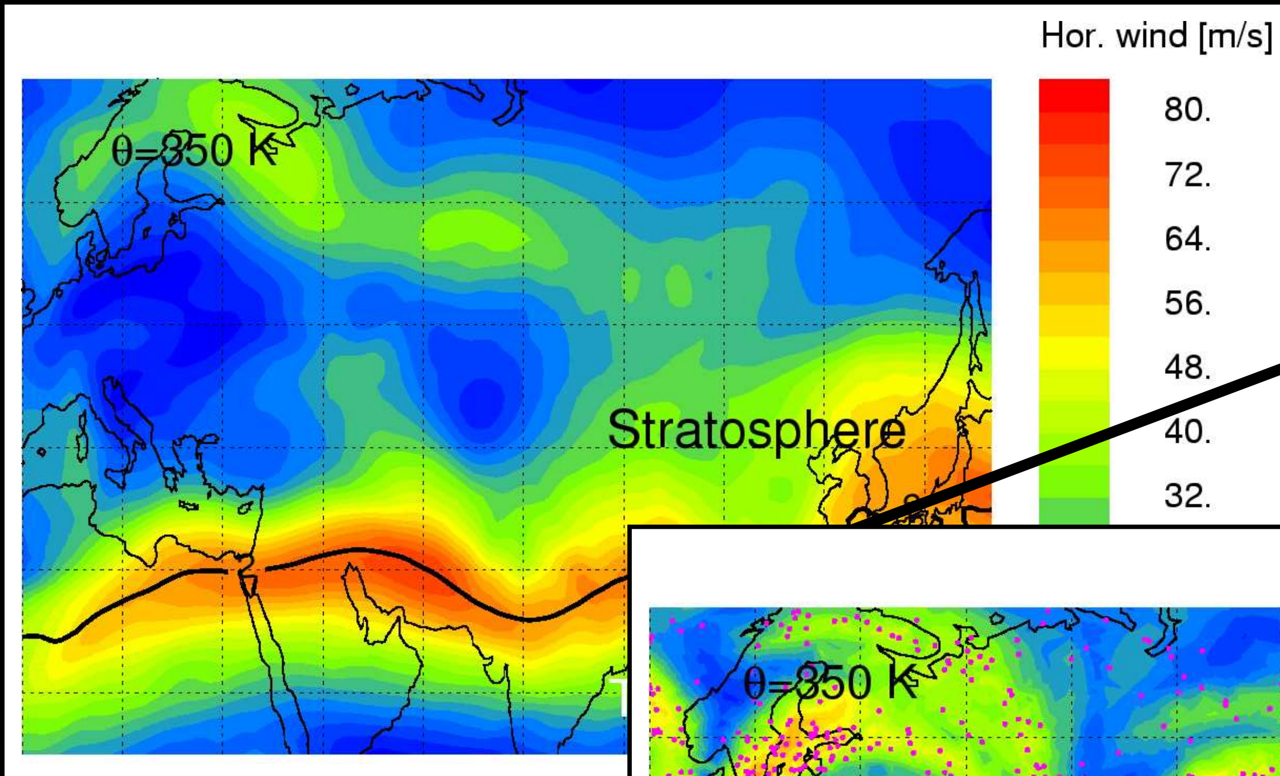
Hurricane Ivan from space shuttle (NASA)

Mixing in the vicinity of the subtropical jet

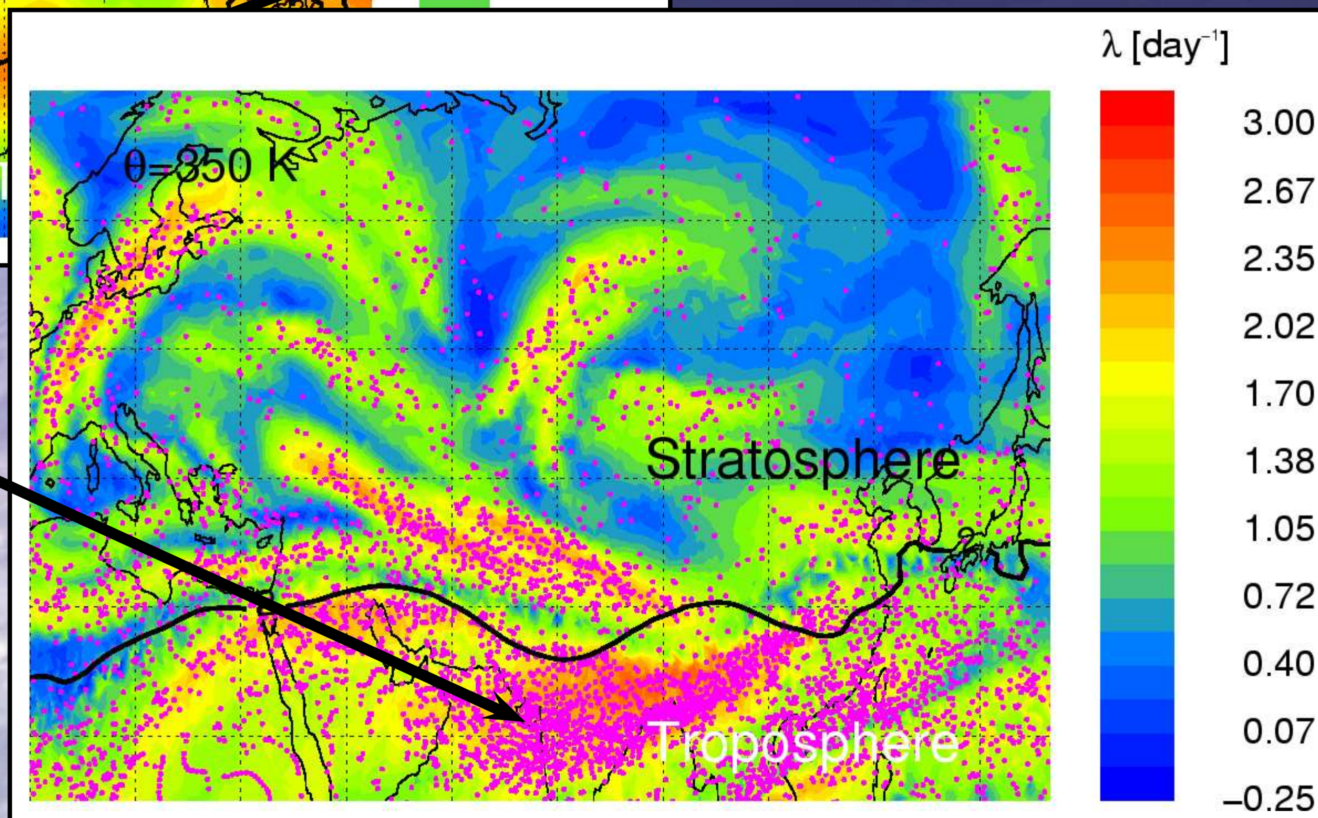


Hurricane Ivan from space shuttle (NASA)

Mixing in the vicinity of the subtropical jet



Subtropical jet over Himalayas



... and mixing !

Pan et al., 2006, JGR

Hurricane Ivan from space shuttle (NASA)

Mixing in CLaMS

Lagrangian realization of Smagorinsky idea,
Mon. Wea. Rev, 1963

$D \sim \nabla \times \mathbf{u}$, i.e. $D \sim$ shear and strain rates

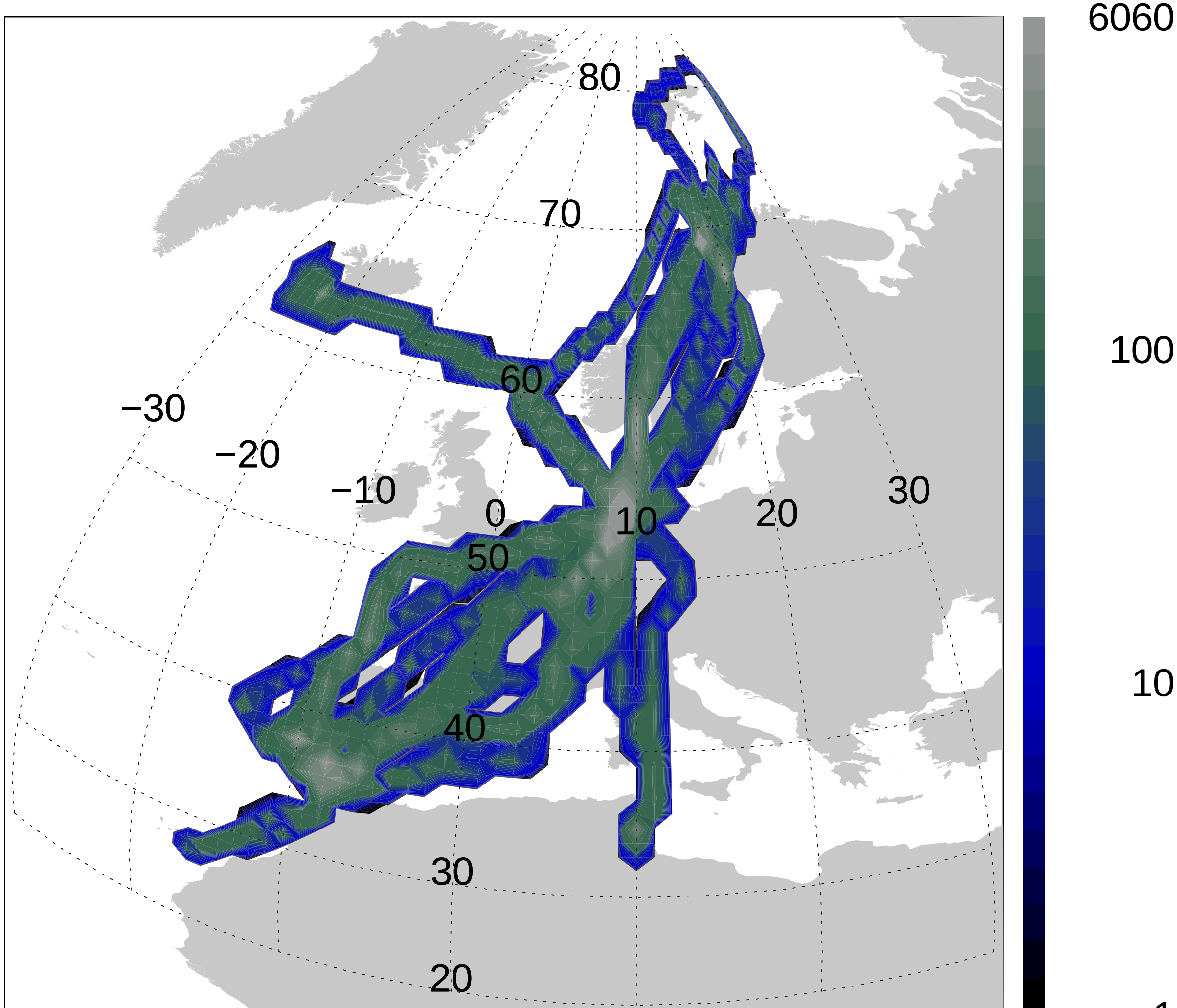
(in Eulerian models: $D \sim \mathbf{u}$, Courant at al., Math Annalen, 1928)

Mixing in CLaMS is driven by vertical shear and horizontal strain rates ($\Rightarrow$ inhomogeneous in time and space)

(in Eulerian models: homogenous mixing with $D_{\rm Euler} \approx 100 D_{\rm CLaMS}$)

CLaMS versus SPURT

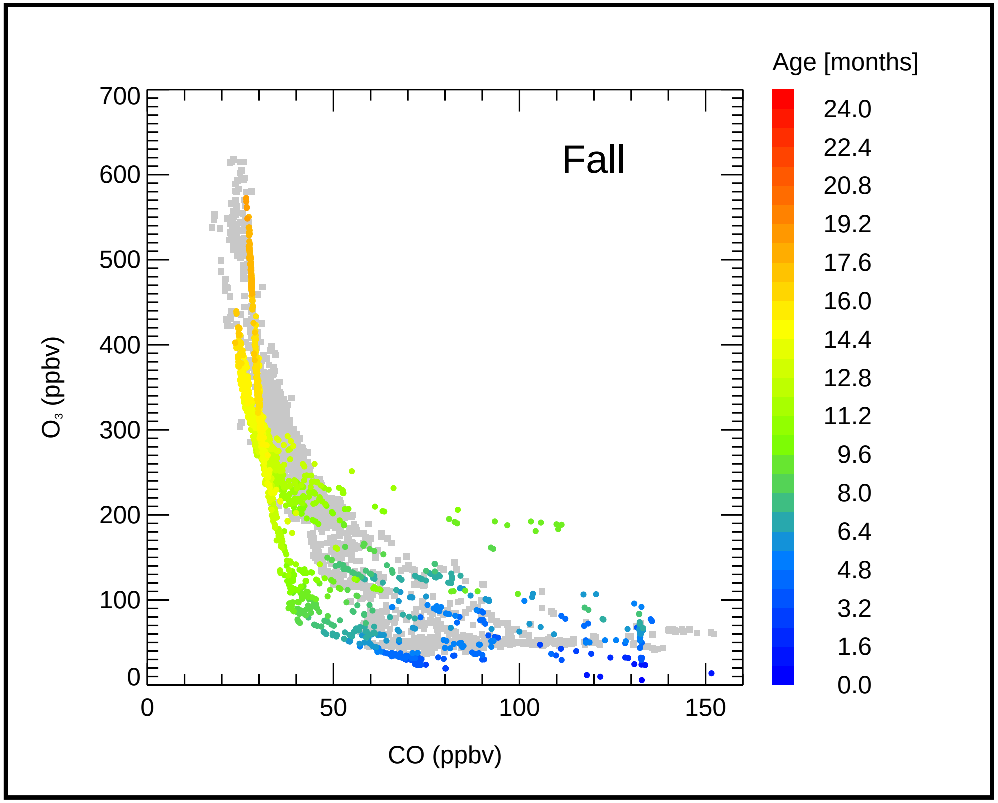
measurements distribution



- SPURT - seasonality of the trace gas transport in the UTLS
- 8 campaigns, 36 flights
- Ozone, CO, H_2O, CO_2, CH_4, NO_y...
- Overview: Engel et al., ACP, 2006
- Mixing layer and its seasonality: Hoor et al., JGR, 2002, GRL 2005, ACP, 2006
  Krebsbach et al., ACP, 2006

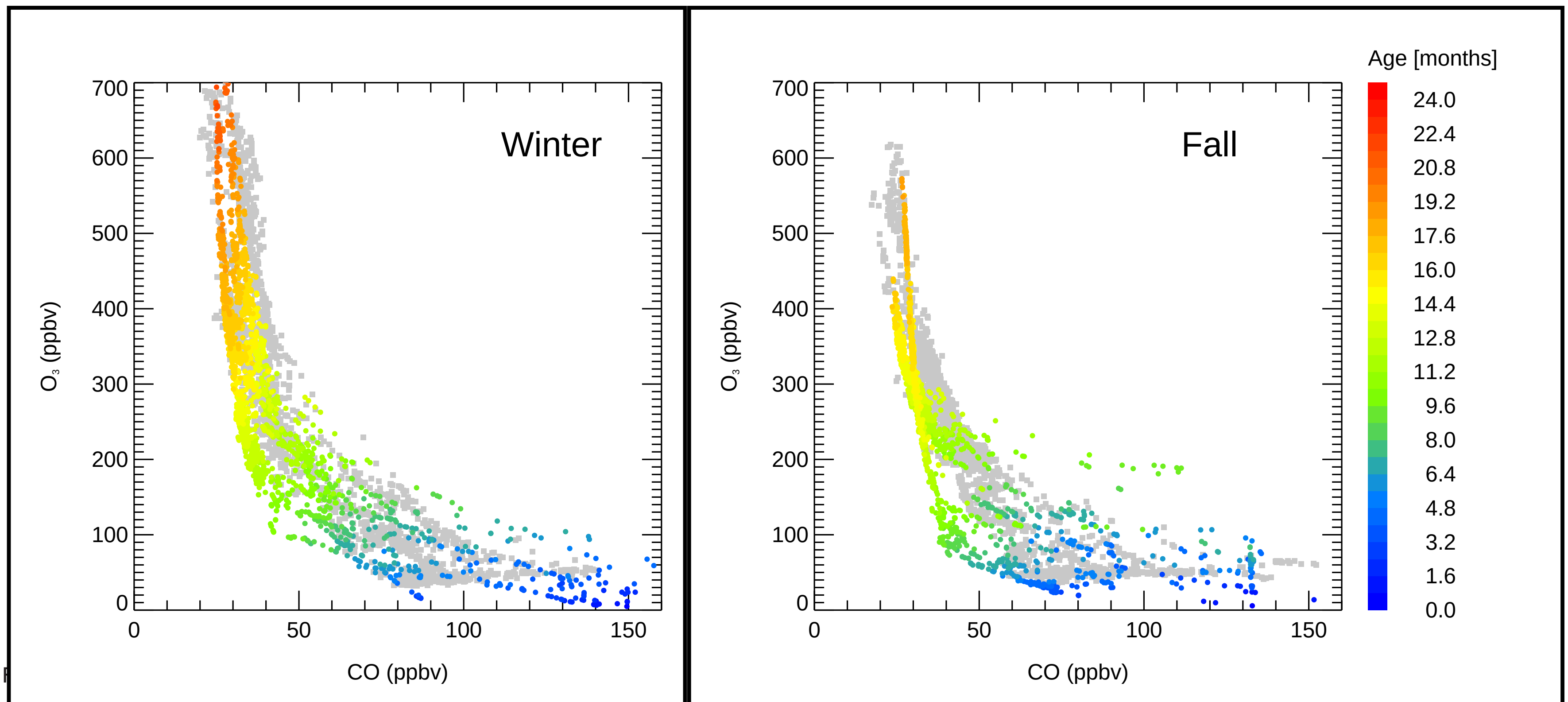
CLaMS versus SPURT

CO/O_3 correlations
Oservations: gray
CLaMS: colored with the mean age

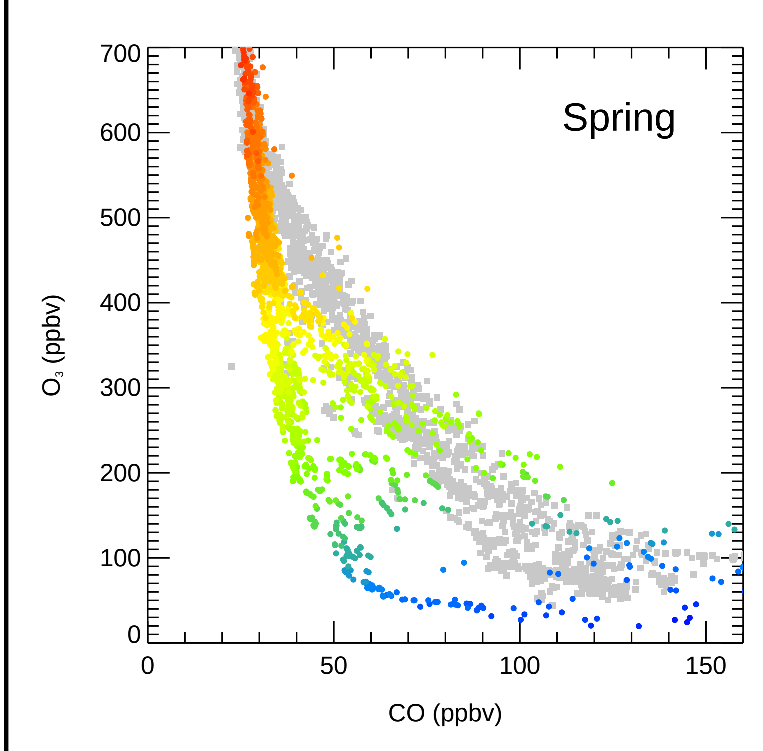


CLaMS versus SPURT

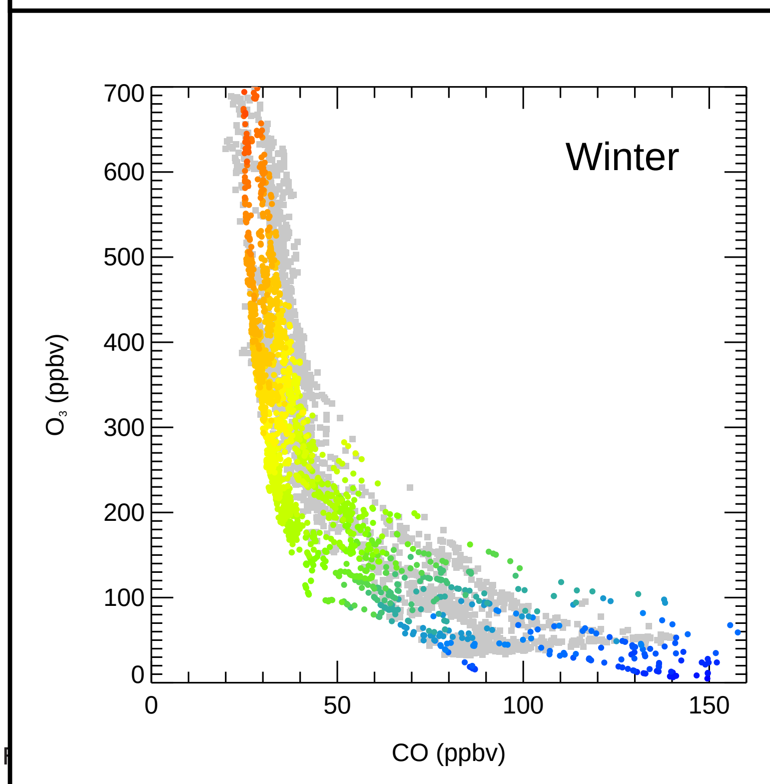
CO/O_3 correlations
Oservations: gray
CLaMS: colored with the mean age

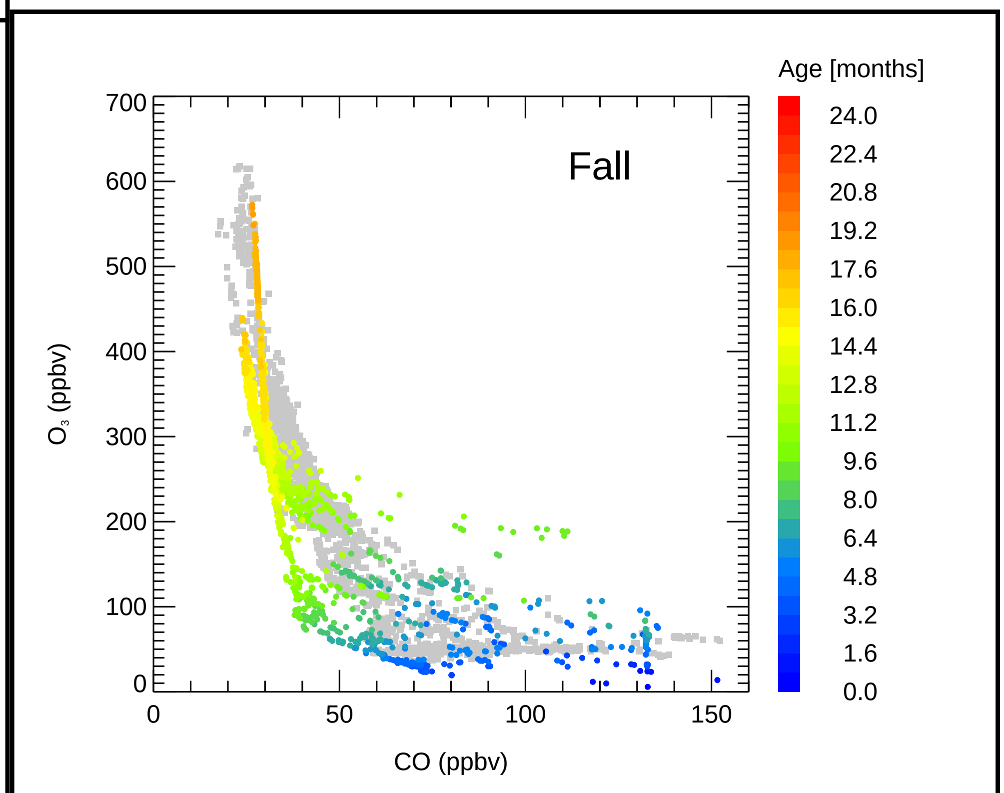


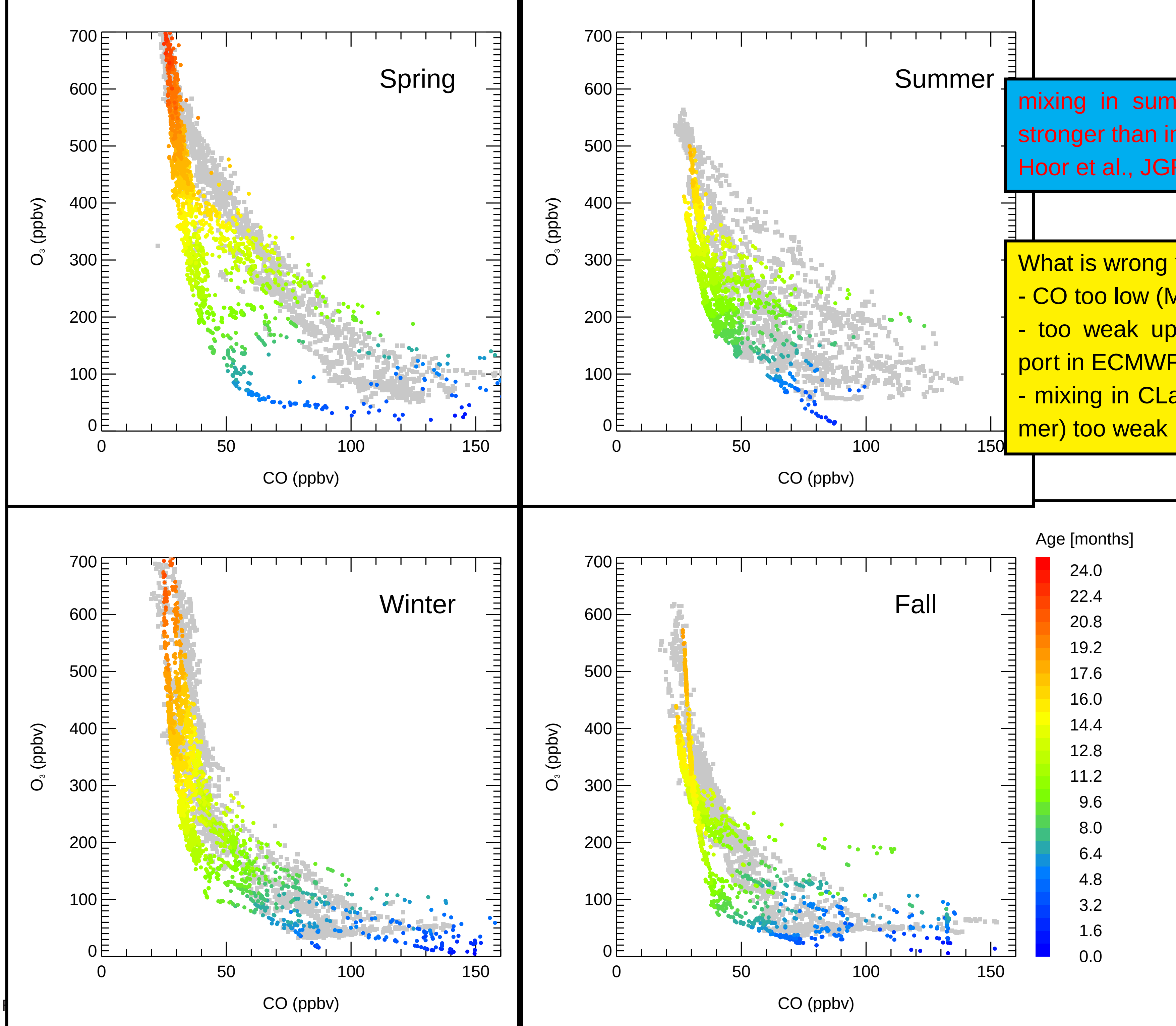
S versus SPURT



CO/O$_3$ correlations
Oservations: gray
CLaMS: colored with the mean age





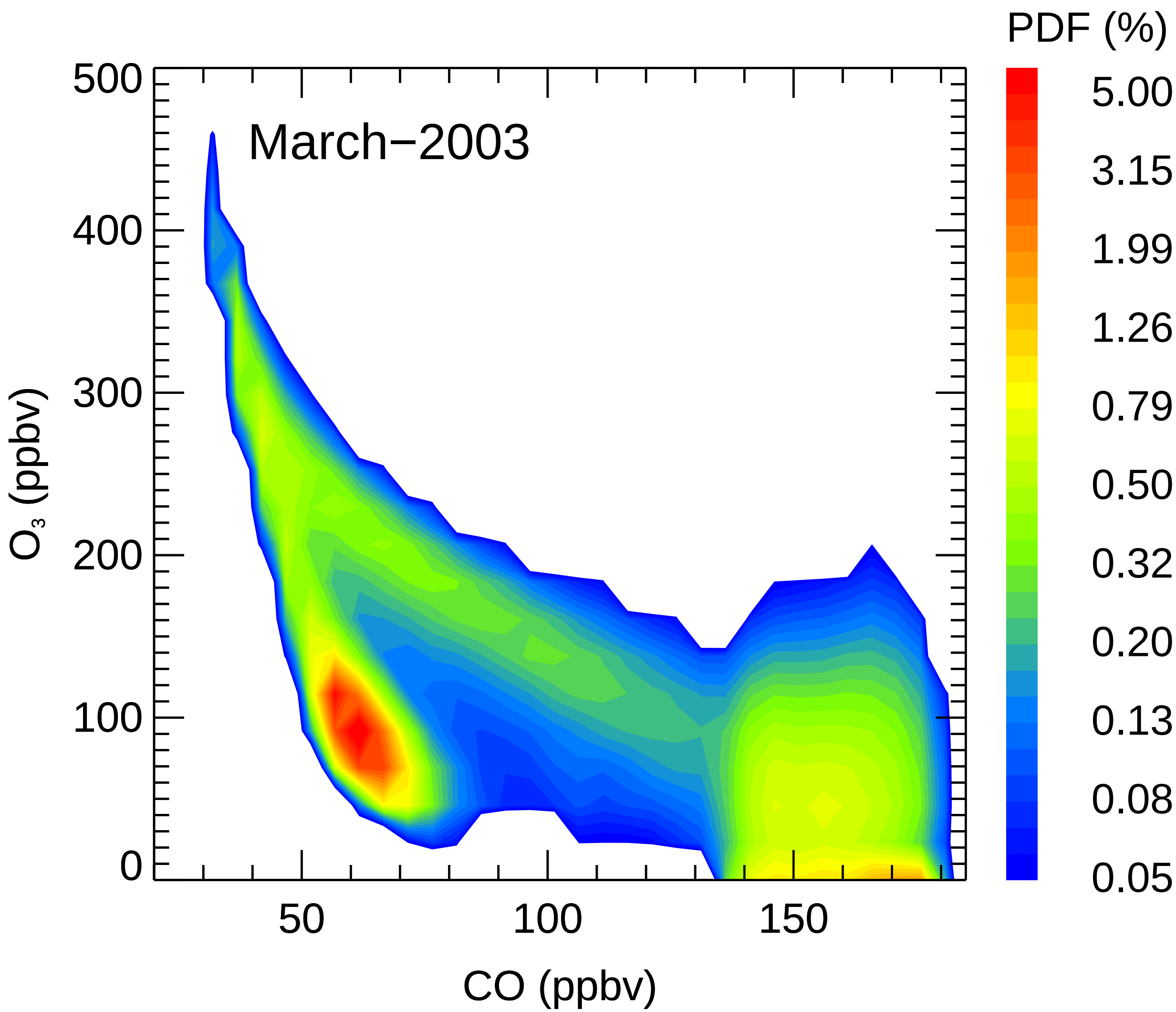


mixing in summer (spring) stronger than in winter (fall)
Hoor et al., JGR, 2002

What is wrong ?
- CO too low (MOPITT)
- too weak upwards transport in ECMWF
- mixing in CLaMS (in summer) too weak

Seasonality of CO/O_3 correlations

Correlation within the mixing layer:
northern hemisphere
$\theta < 380$ K
$1 <$PV< 3 PVU



Seasonality of CO/O_3 correlations

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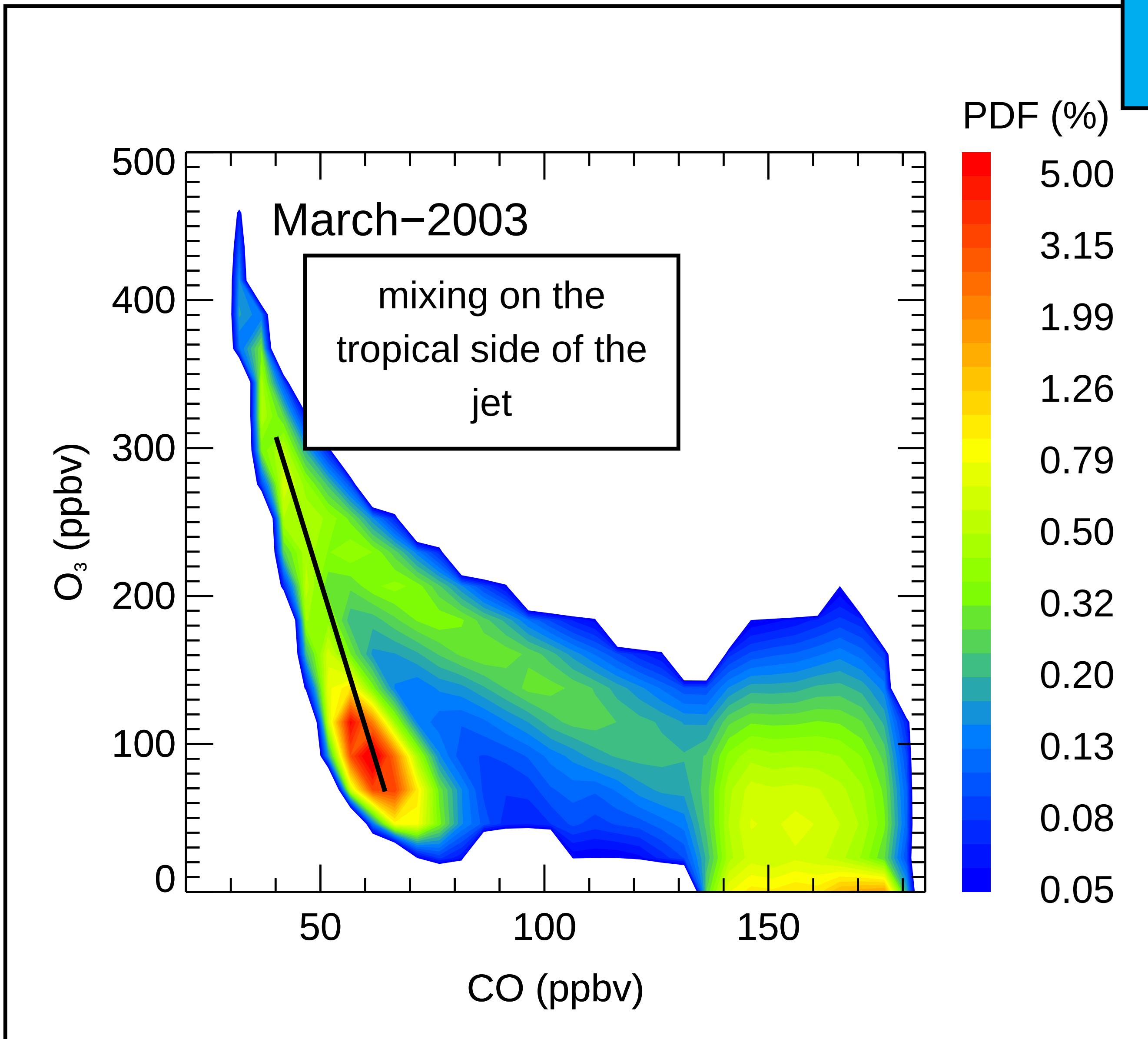
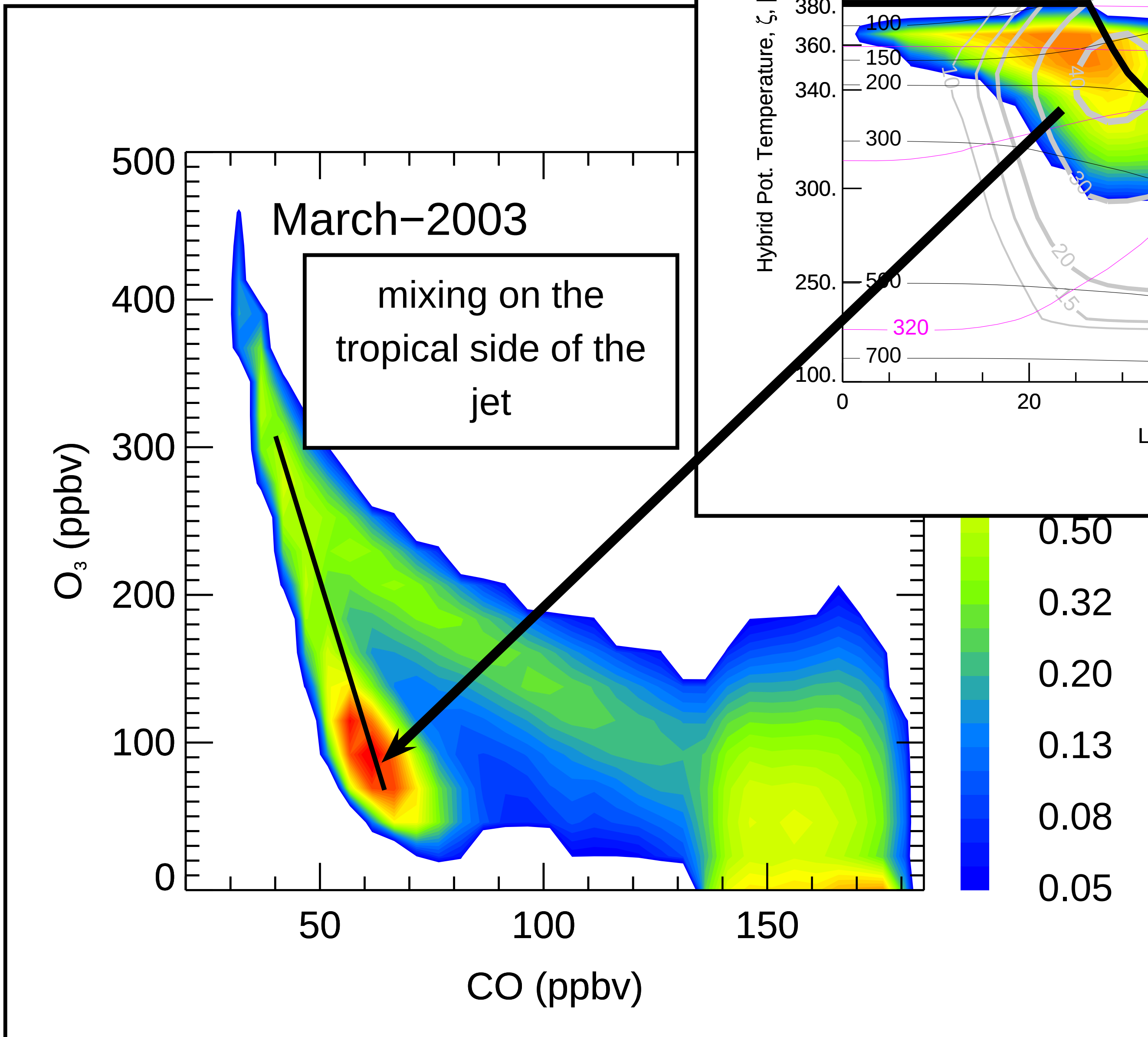
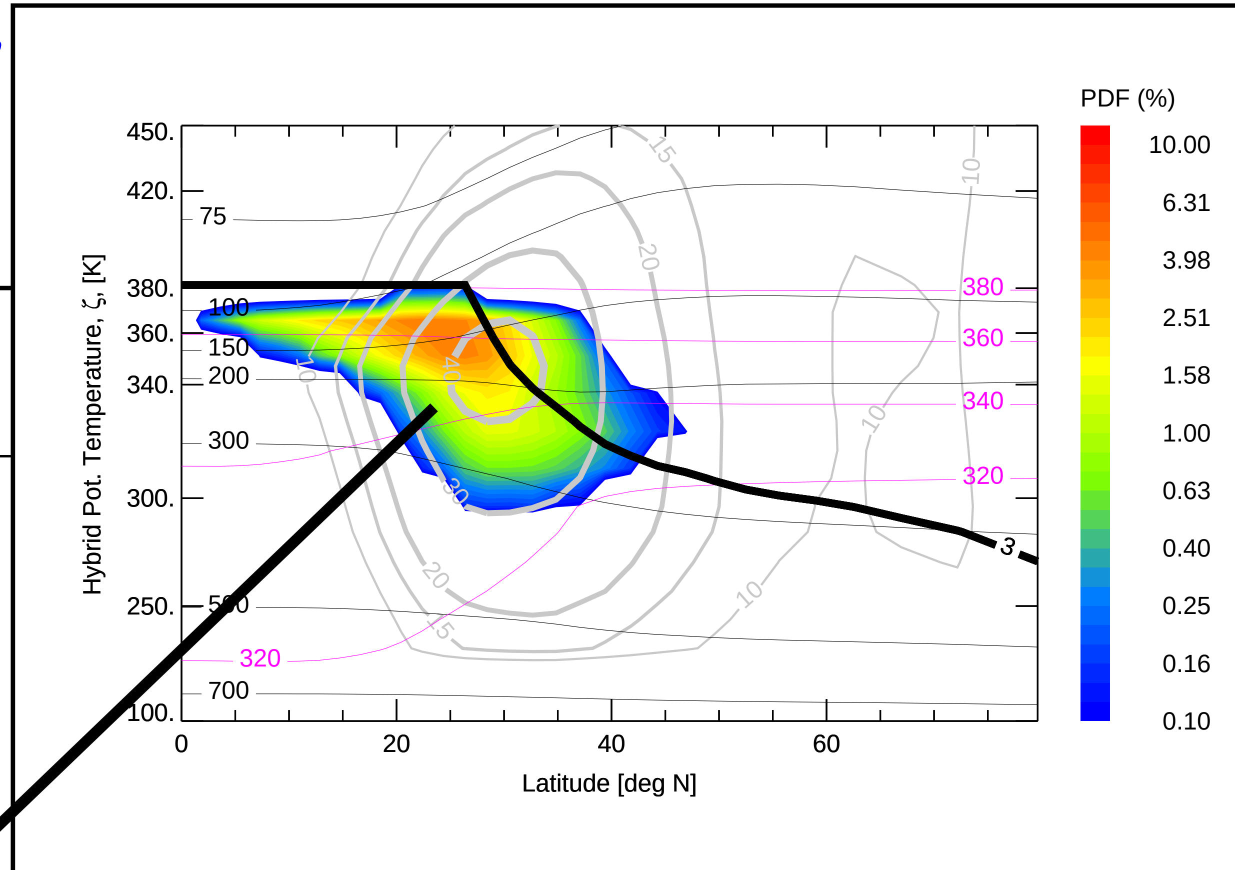


Seasonality

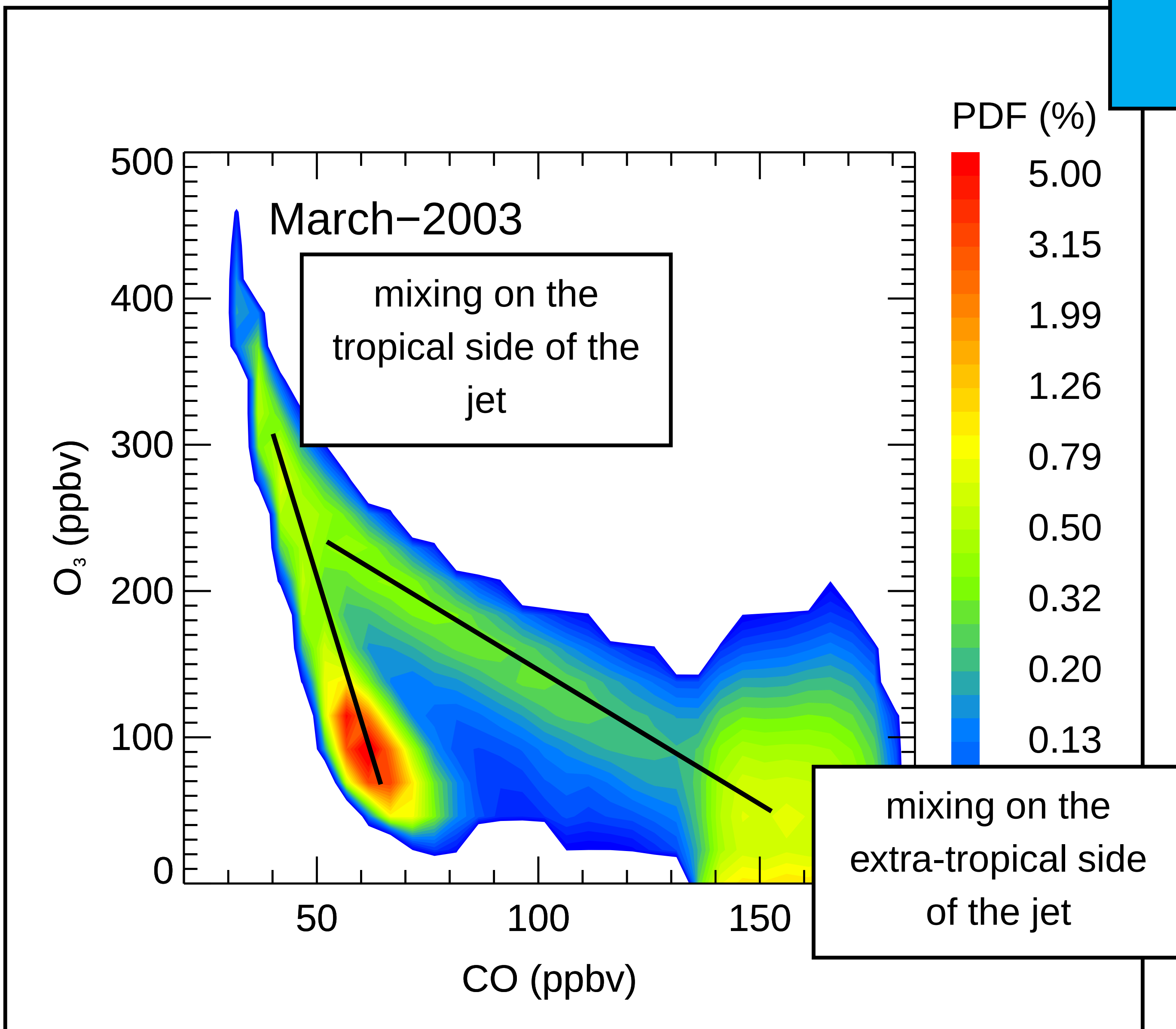




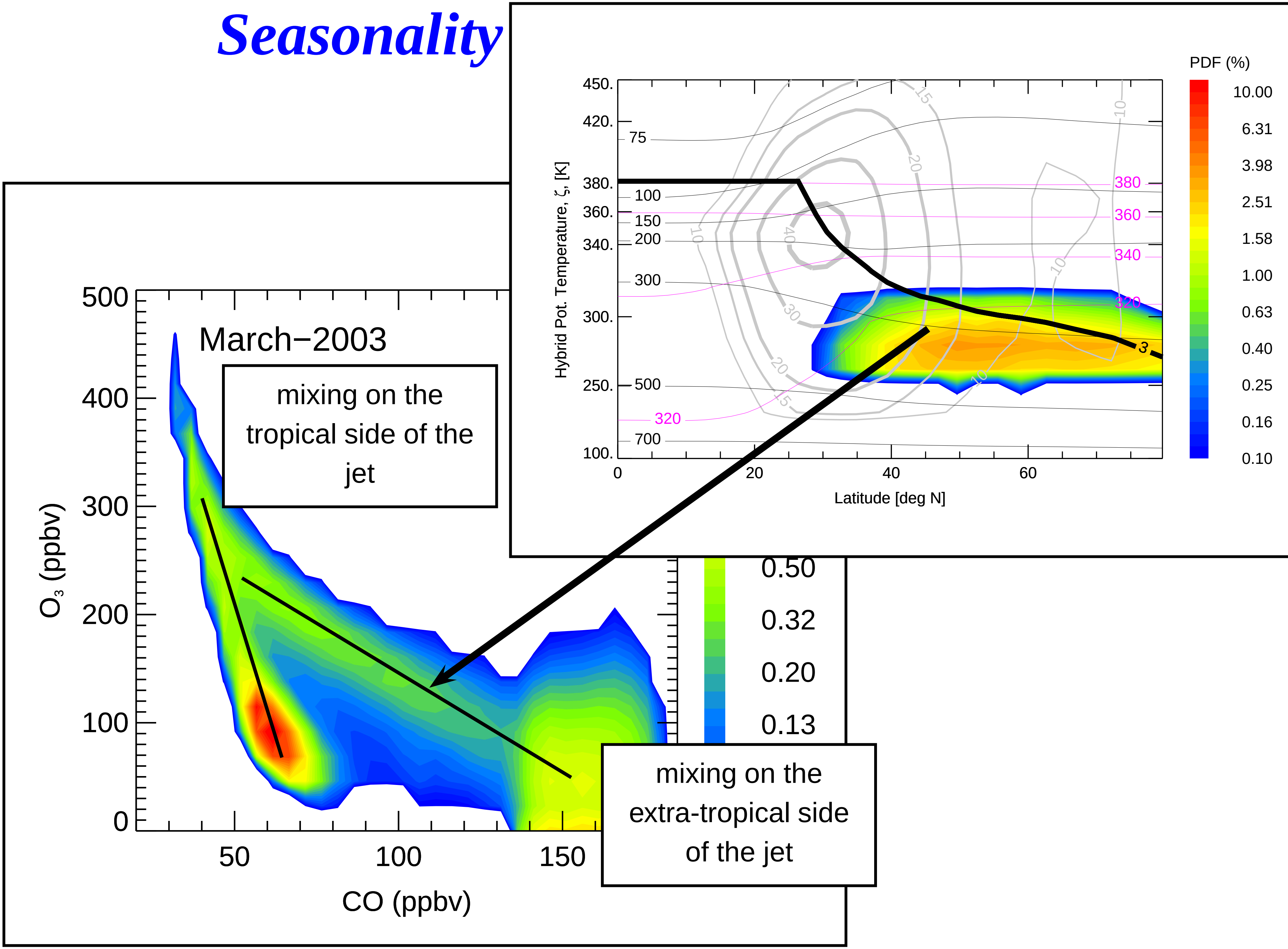
50<CO<70 ppbv
80<O_3<100 ppbv

Seasonality of CO/O_3 correlations

Correlation within the mixing layer:
northern hemisphere
$\theta < 380$ K
$1 <$PV< 3 PVU



Seasonality



Seasonality of CO/O_3 correlations

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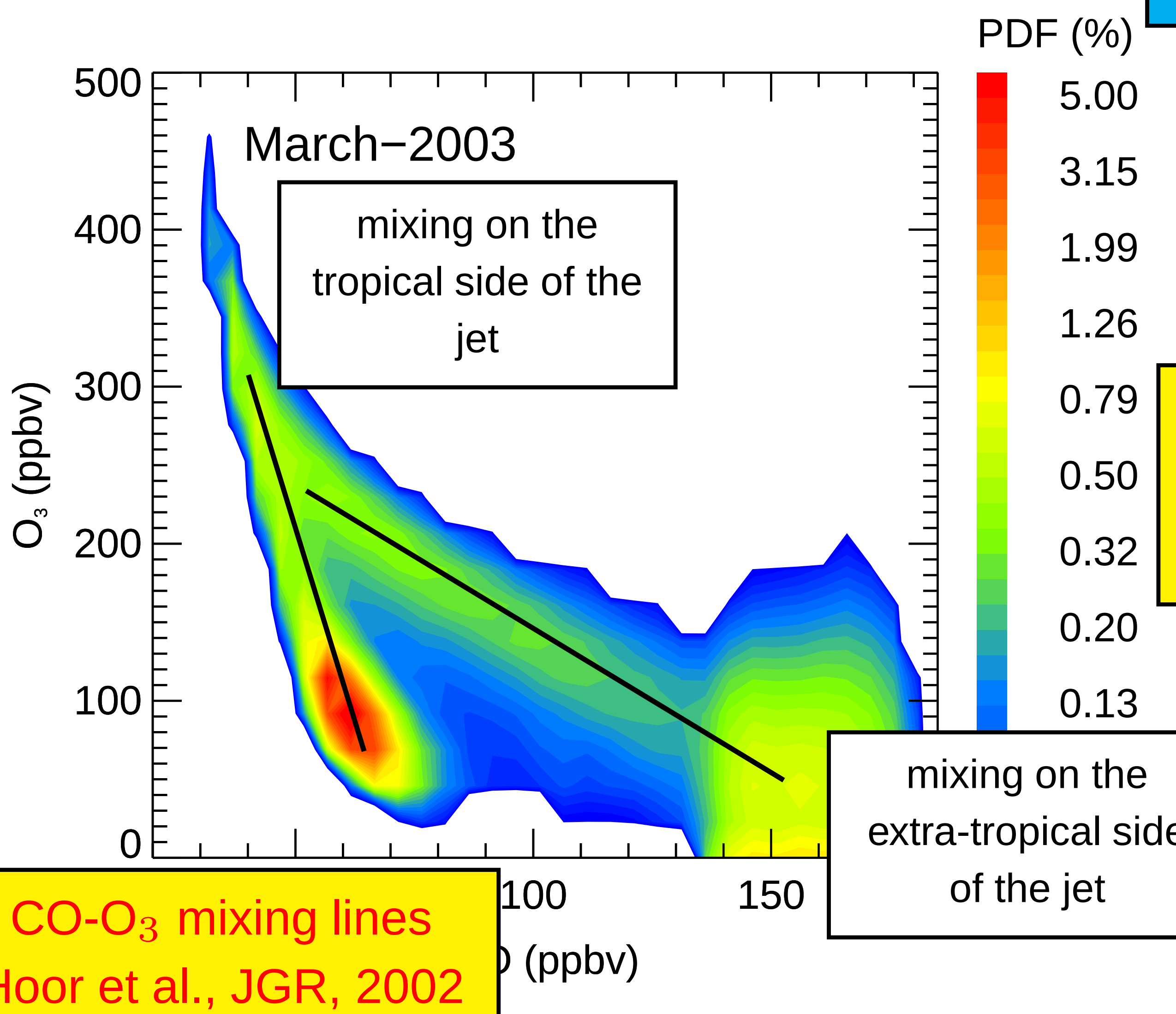
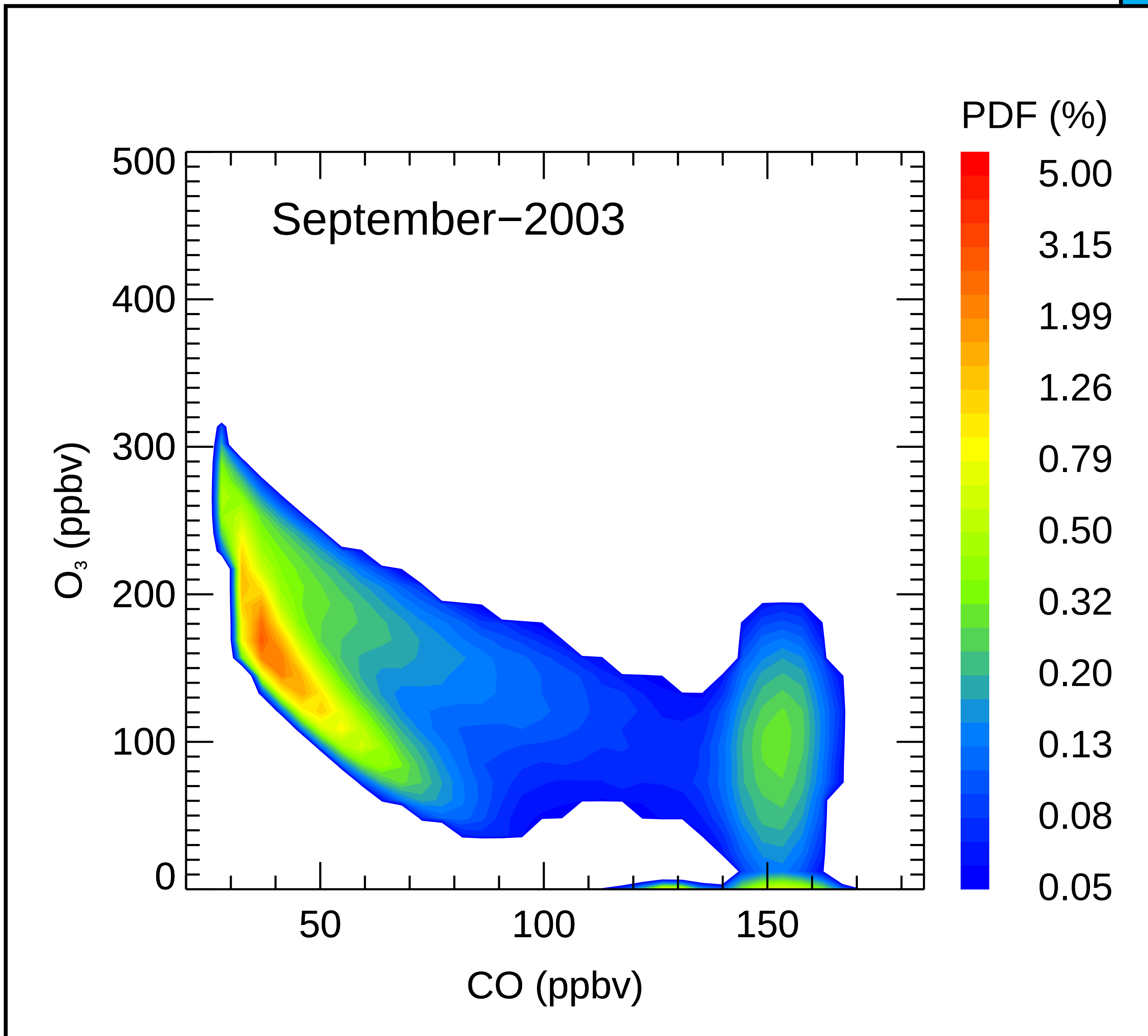


Jet as a transport barrier in winter and spring
Ray et al., JGR, 2004

CO-O_3 mixing lines
Hoor et al., JGR, 2002

Seasonality of CO/O_3 correlations

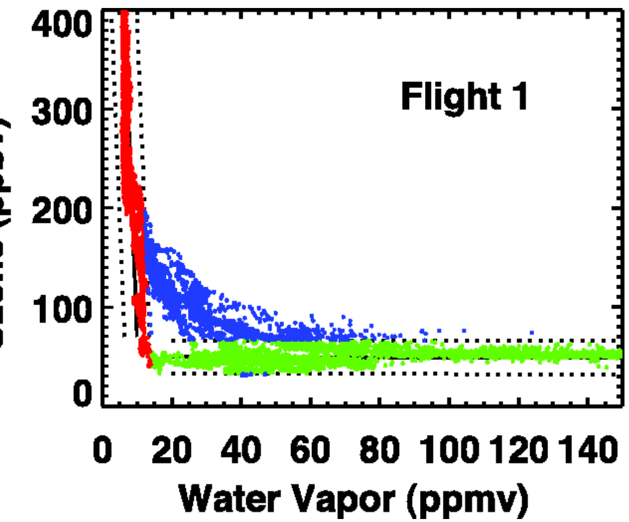
Correlation within the mixing layer:
northern hemisphere
$\theta < 380$ K
$1 <$PV< 3 PVU

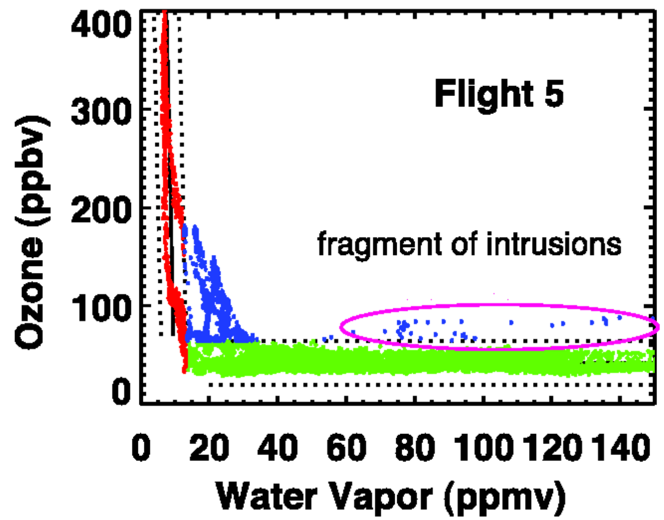


...but not during summer and fall

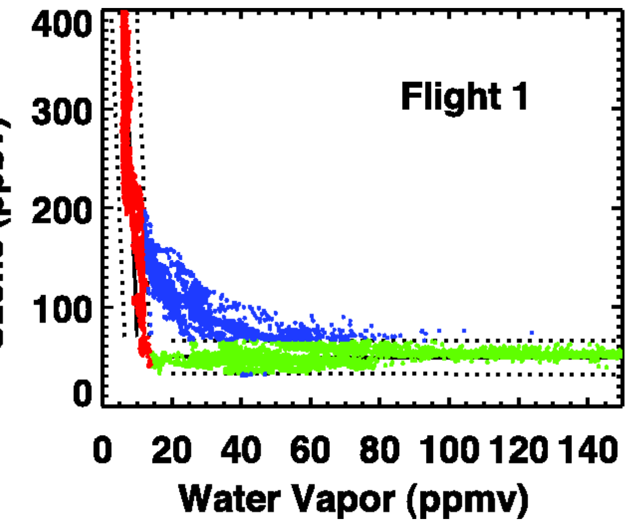
...CLaMS and START-05...

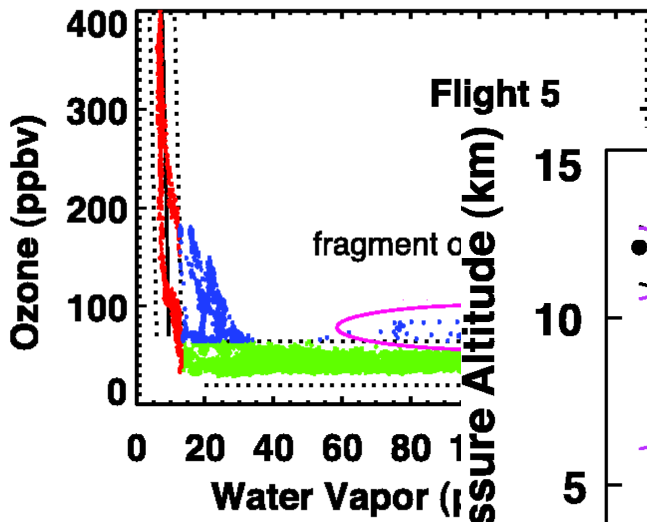
START-05: H2O-Ozone correlations

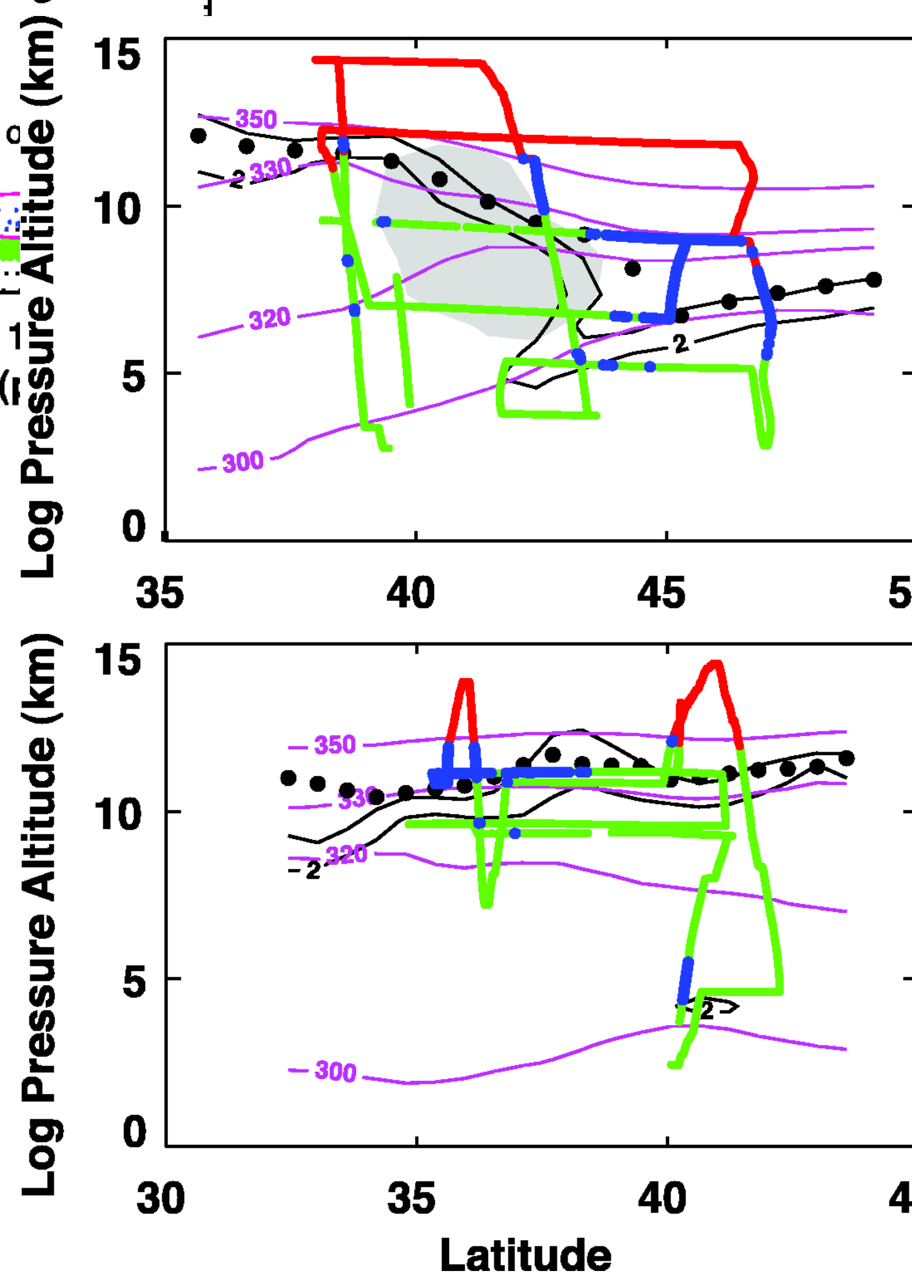




START-05: H2O-Ozone correlations







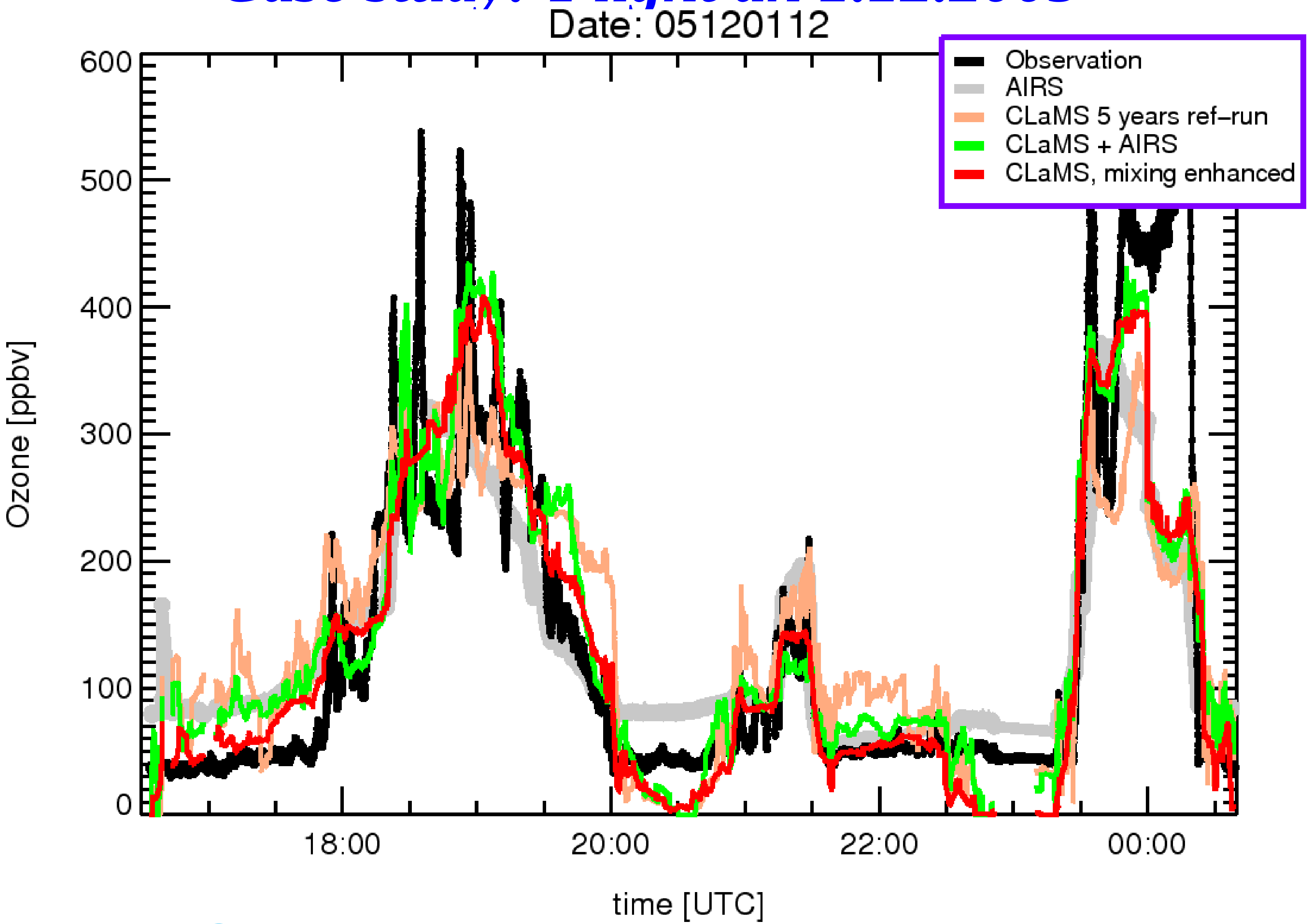
Pan et al., JGR, 2007

- enhanced mixing (weaker vertical gradients of tracers, thicker mixing layer) on the cyclonal side of the jet
- weak mixing on the anticyclonal side and far away from the jet (thin mixing layer, enhanced vertical gradients of tracers)

CLaMS Simulations

- 5-years global simulations, hor/vert resolultion 100 km/400 m, troposphere+stratosphere
- Ozone: $\theta > 500$ - HALOE, Boundary layer: set to 0
- H2O: $\theta < 380$ - ECMWF, Upper boundary: HALOE
- Re-Initialization on 25.11.2005 with AIRS ozone
- Nested simulations $10 < lat < 90$N, $\theta < 500$ K up to 50 km hor. resolution
- Sensitivity studies with respect to mixing

Case study: Flight an 1.12.2005



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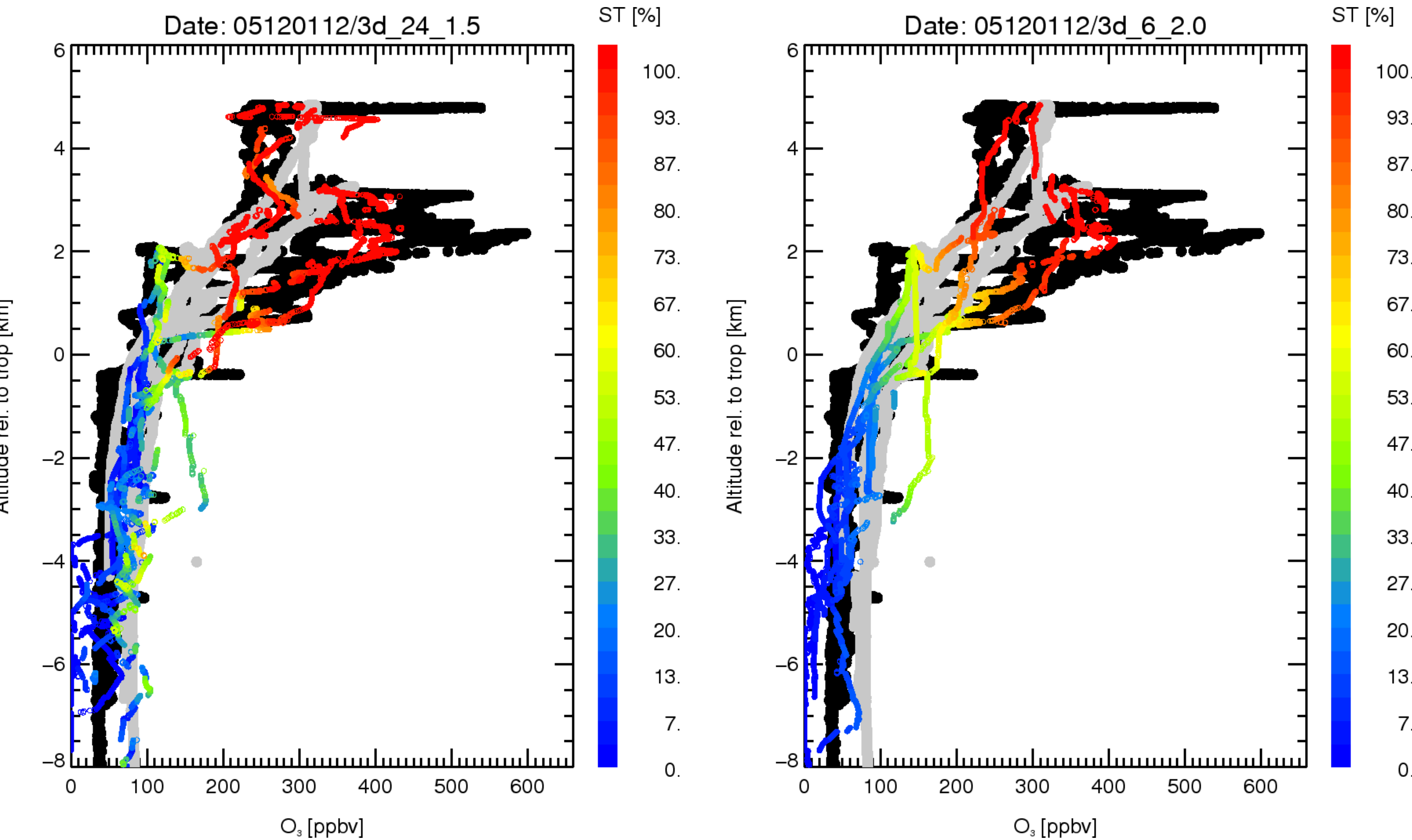
Case study: Flight an 1.12.2005



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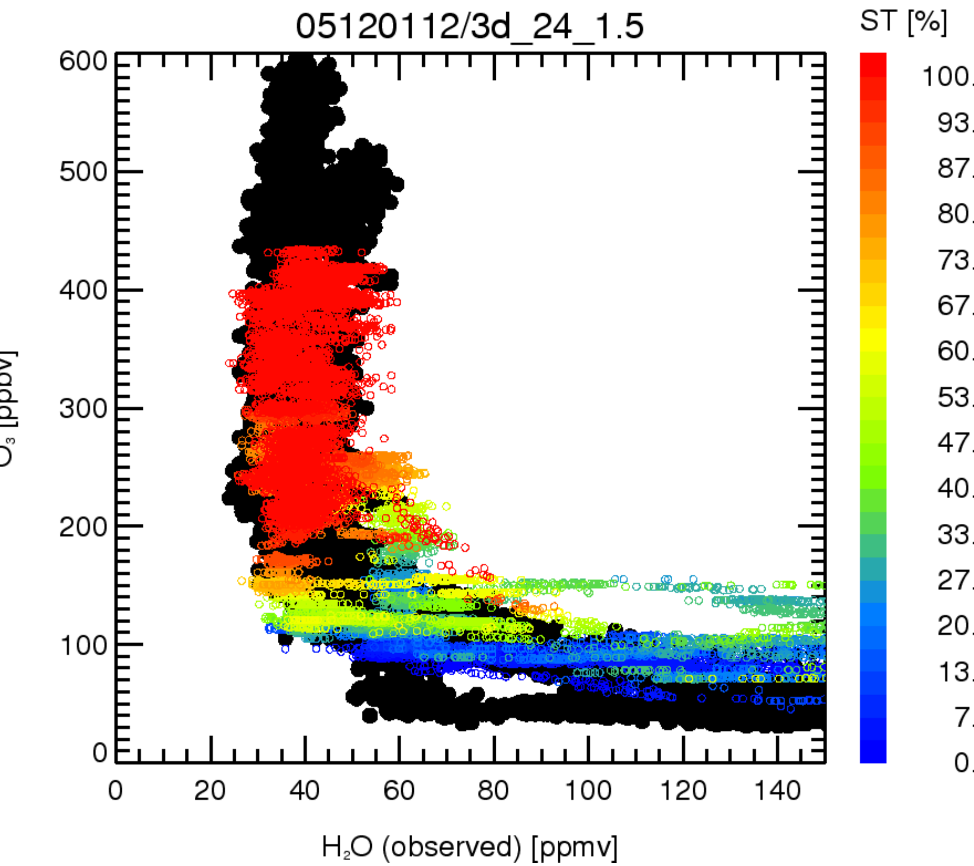
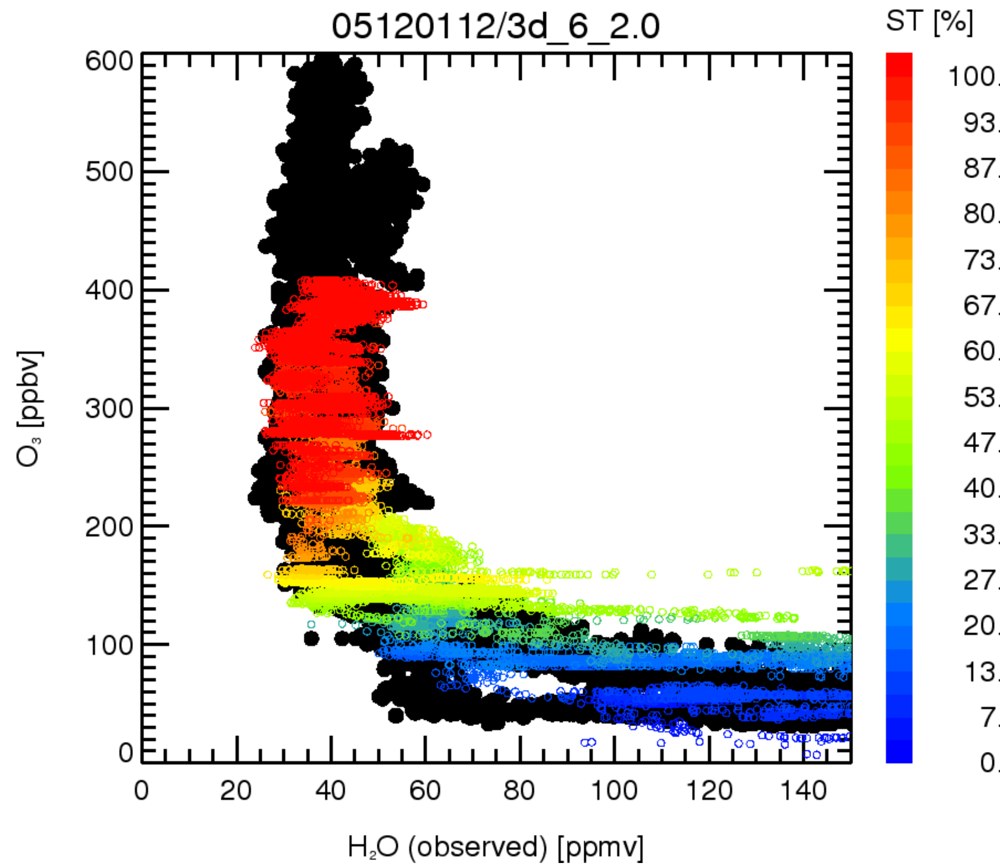
Left: Reference (with AIRS) Right: + enhanced mixing

Case study: Flight an 1.12.2005





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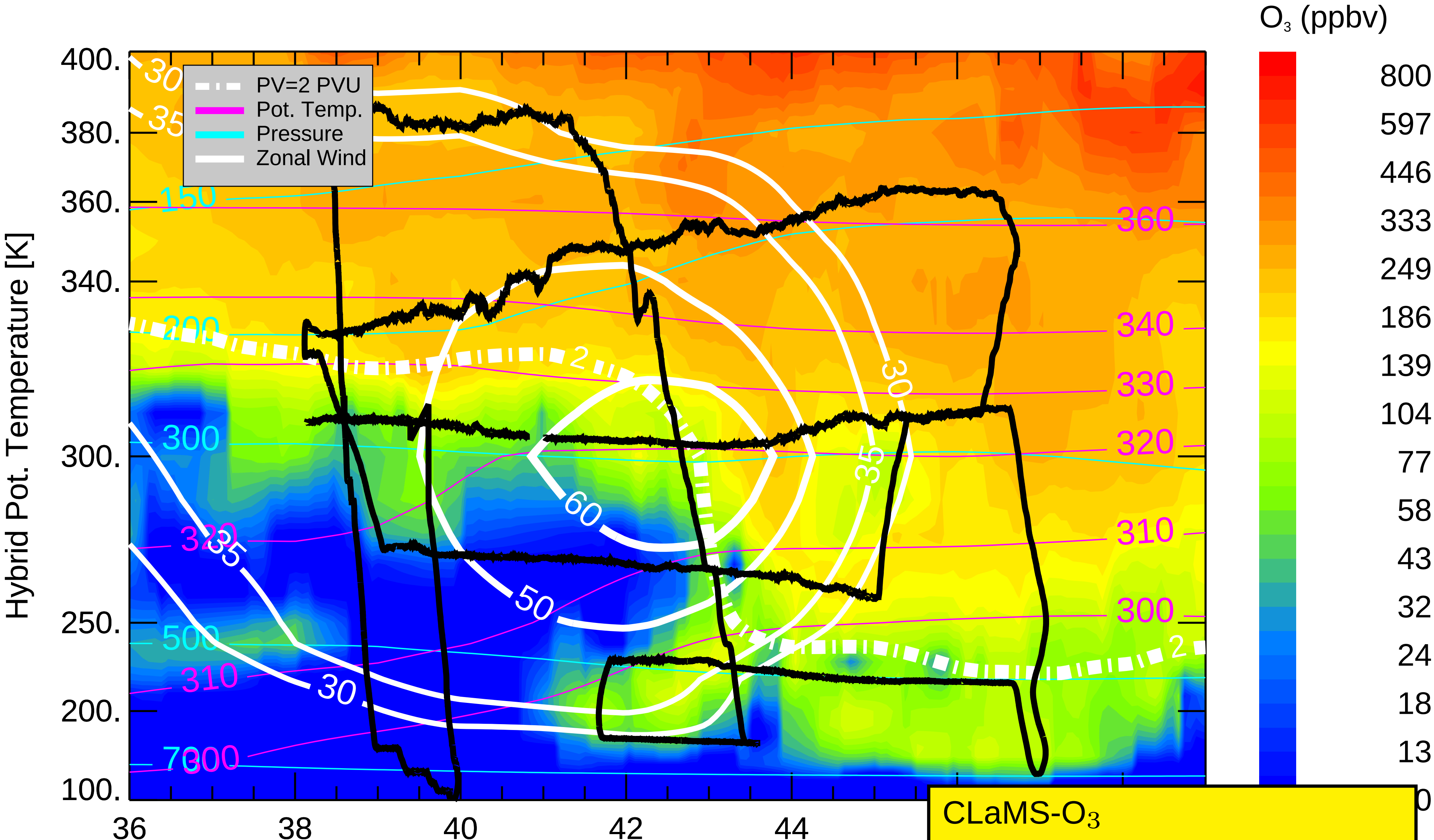

CLaMS-O_3
Reference run (after 4 years)
O_3 in boundary layer set to 0
O_3 at 500 K - HALOE

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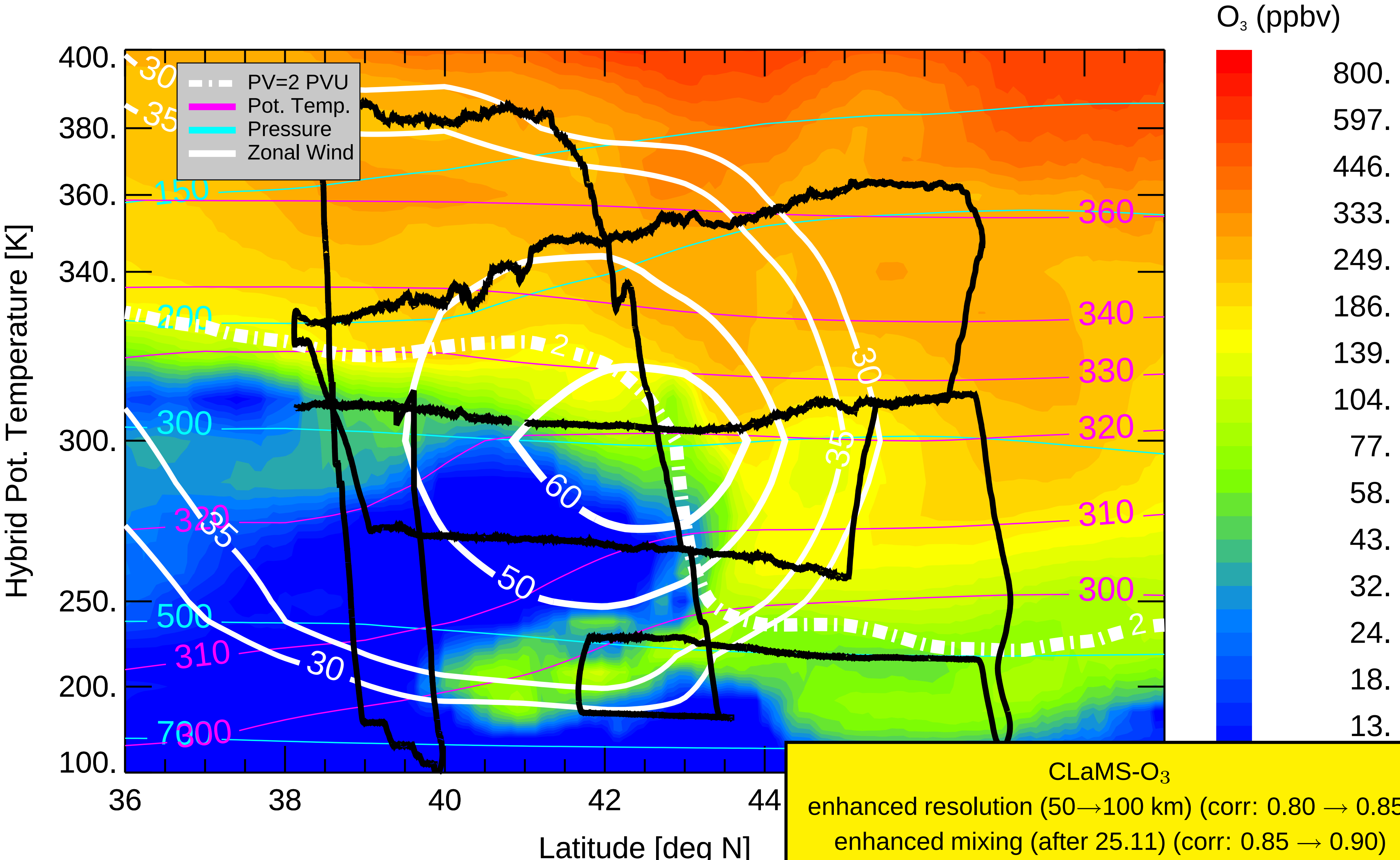
Case study: Flight an 1.12.2005



CLaMS-O_3

enhanced resolution (50→100 km) (corr: 0.80 → 0.85)

enhanced mixing (after 25.11) (corr: 0.85 → 0.90)

Mixing layer thicker on the cyclonal side of the jet

(Pan et al, JGR, 2007)

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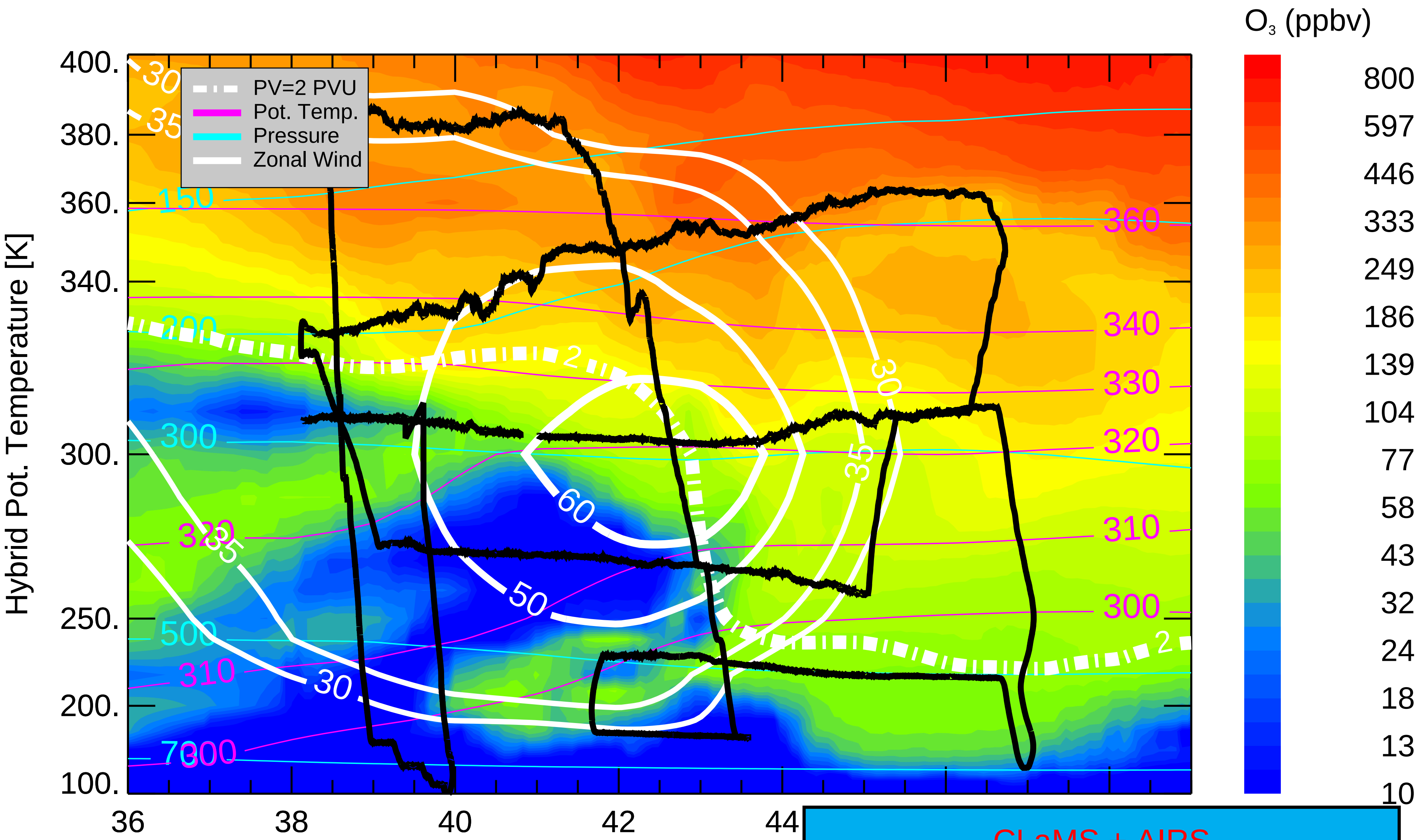
Case study: Flight an 1.12.2005

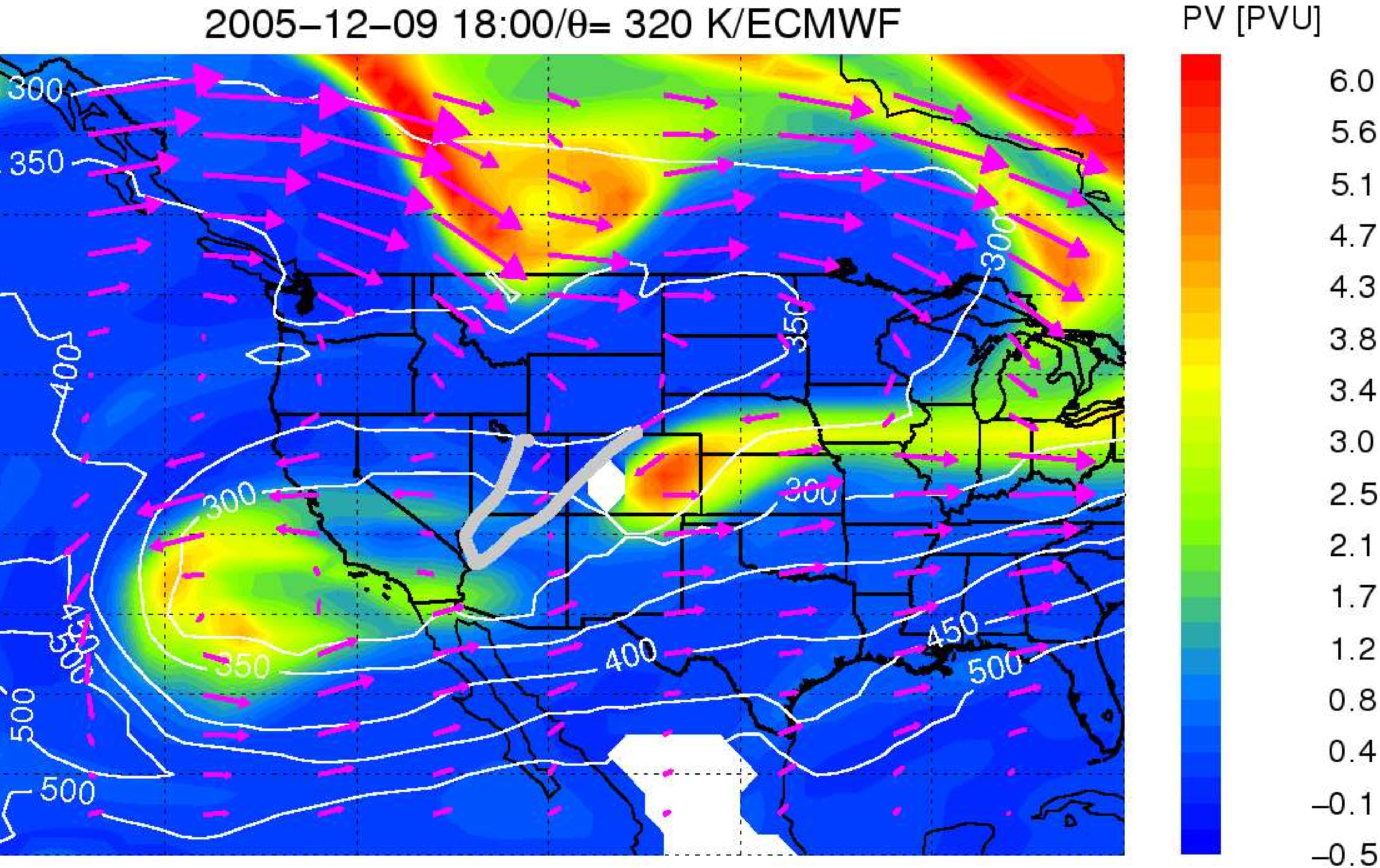


CLaMS + AIRS

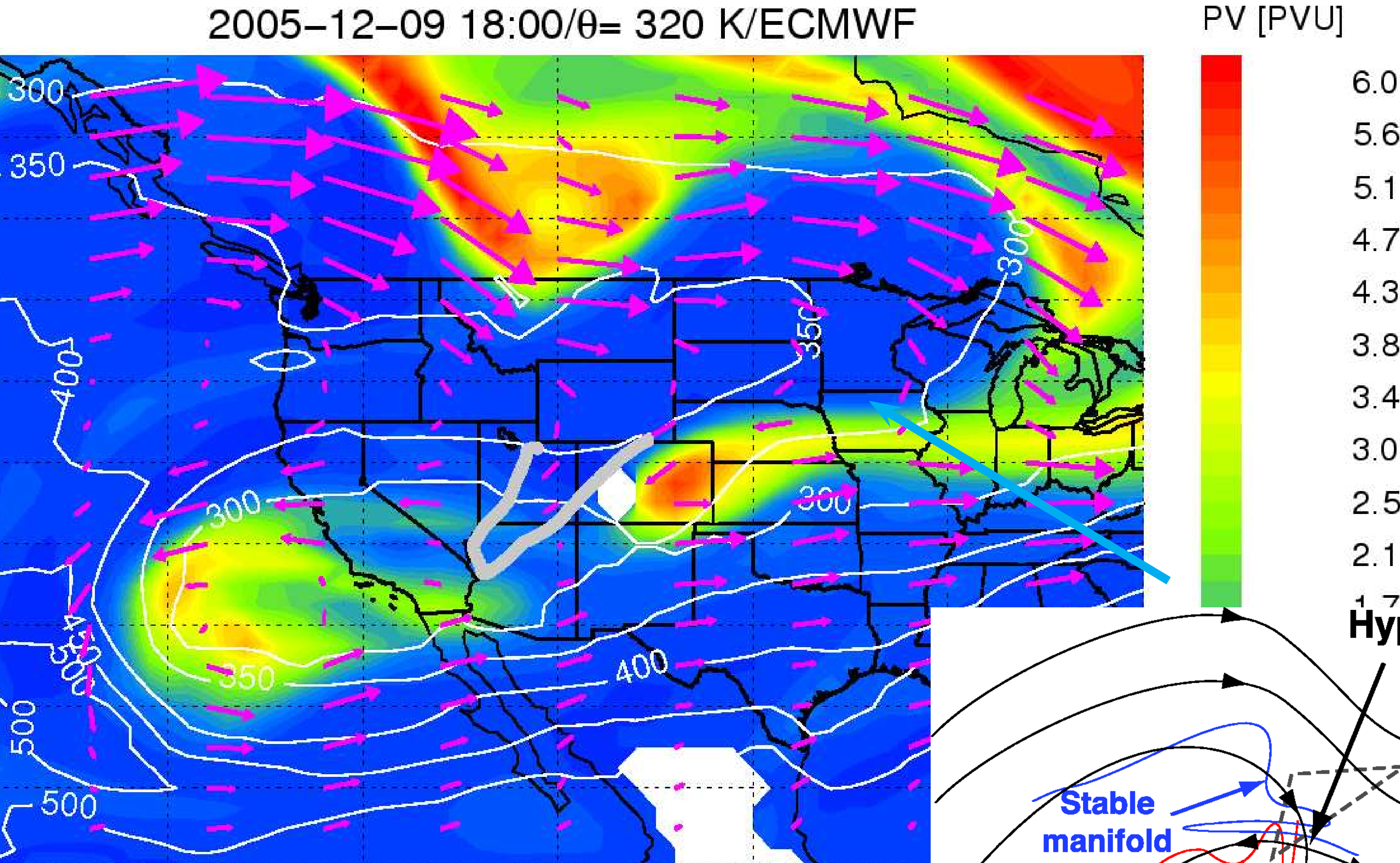
better results in the stratosphere

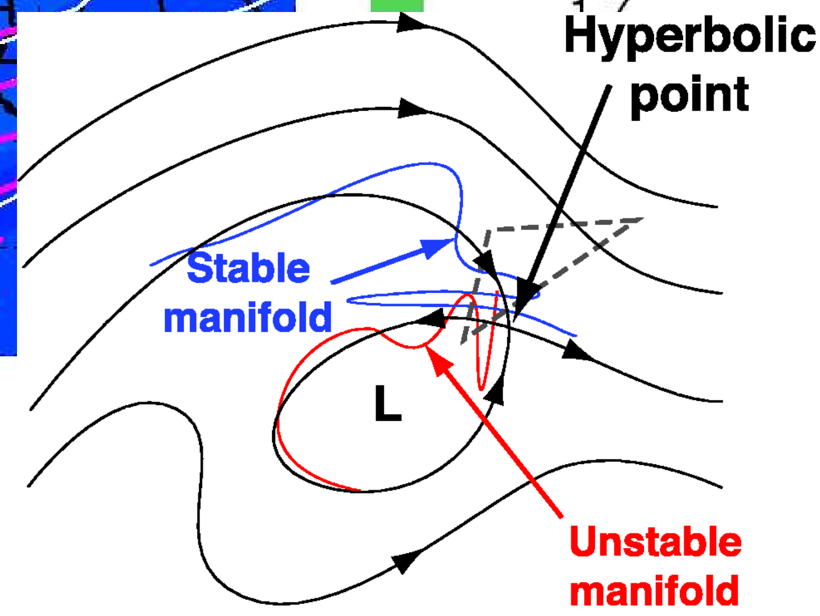
O3 too high in the troposphere !

Flight an 9.12.2005



Flight an 9.12.2005





Hyperbolic point
Enhanced stirring
Bowman et al, JGR, 2007

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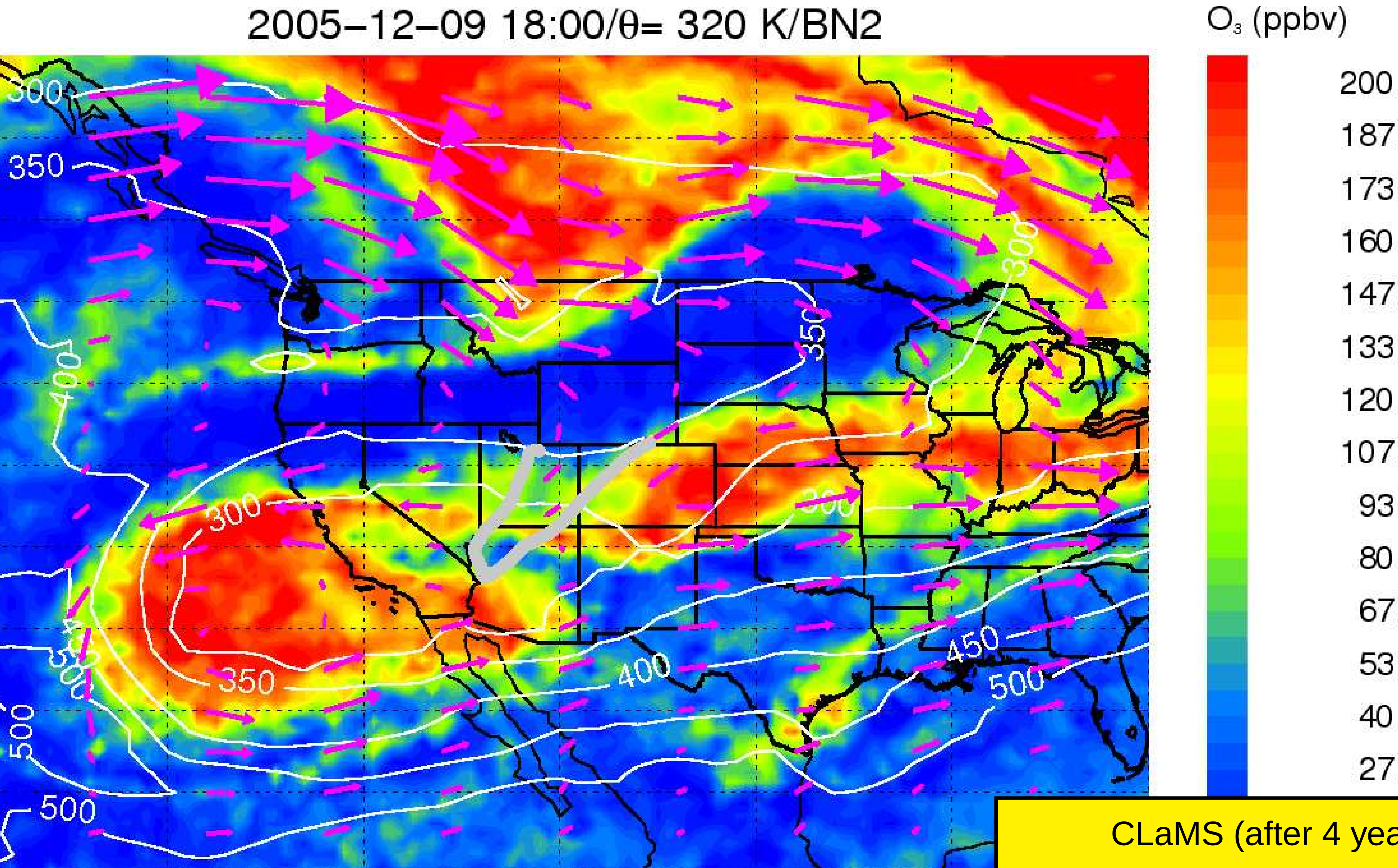
Flight an 9.12.2005



CLaMS (after 4 years):

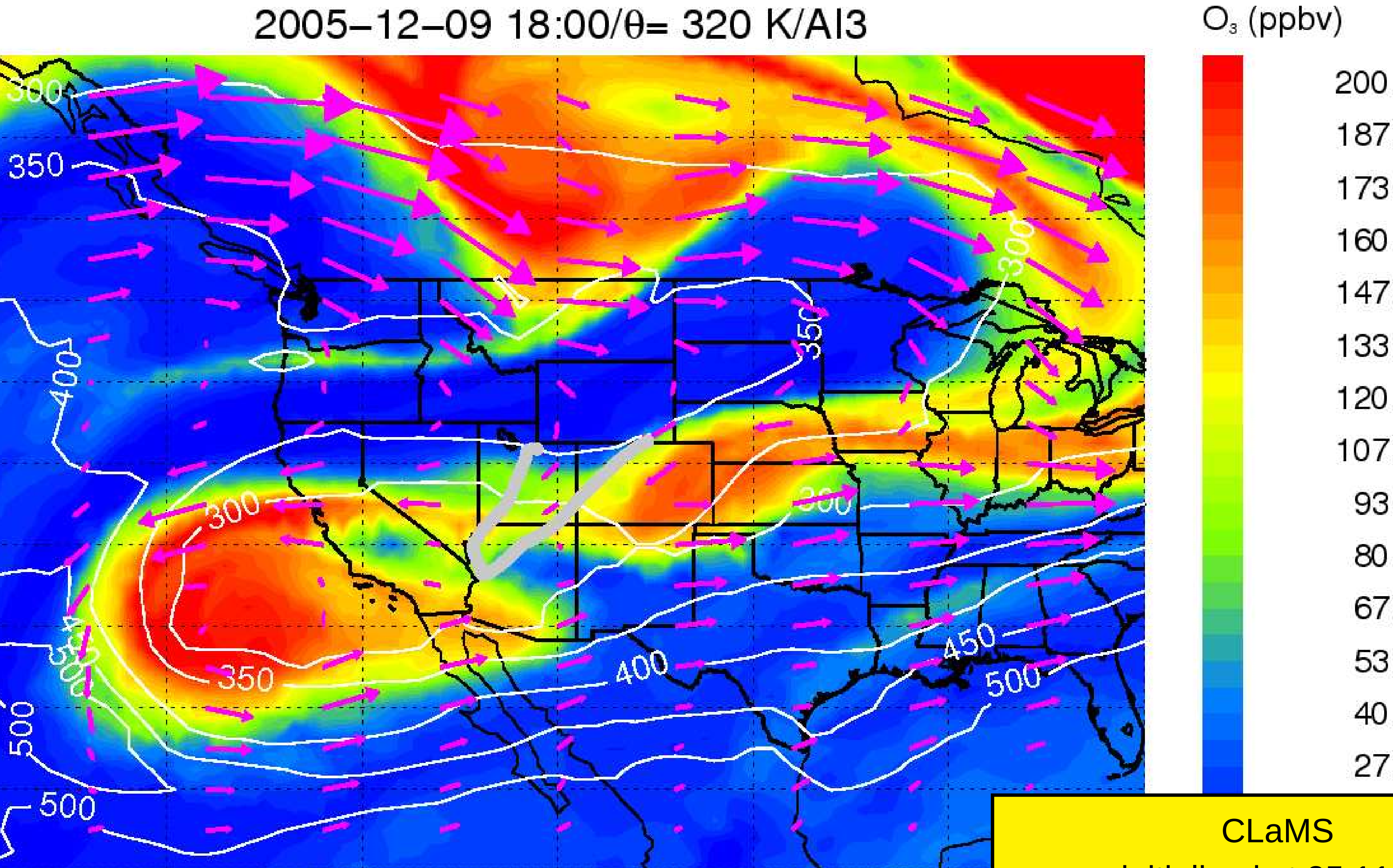
$\theta = 500$ K: (HALOE)

Boundary Layer: Ozone=0

no distruction cycles

$r_0 = 100$ km (global)

Flight an 9.12.2005



CLaMS
re-initialized at 25.11.2005
enhanced mixing
enhanced resolution
$r_0 = 50$ km (nested)

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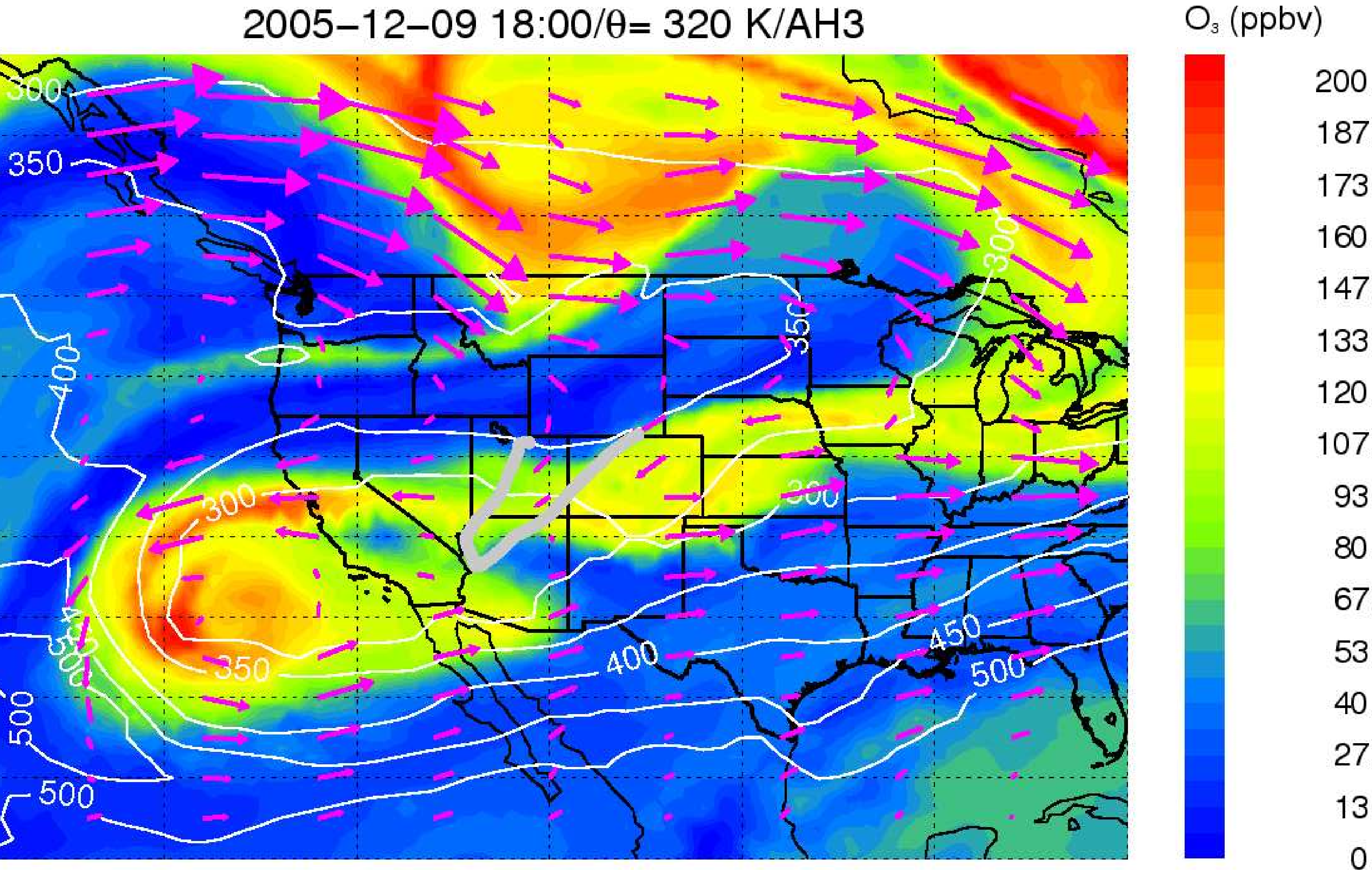
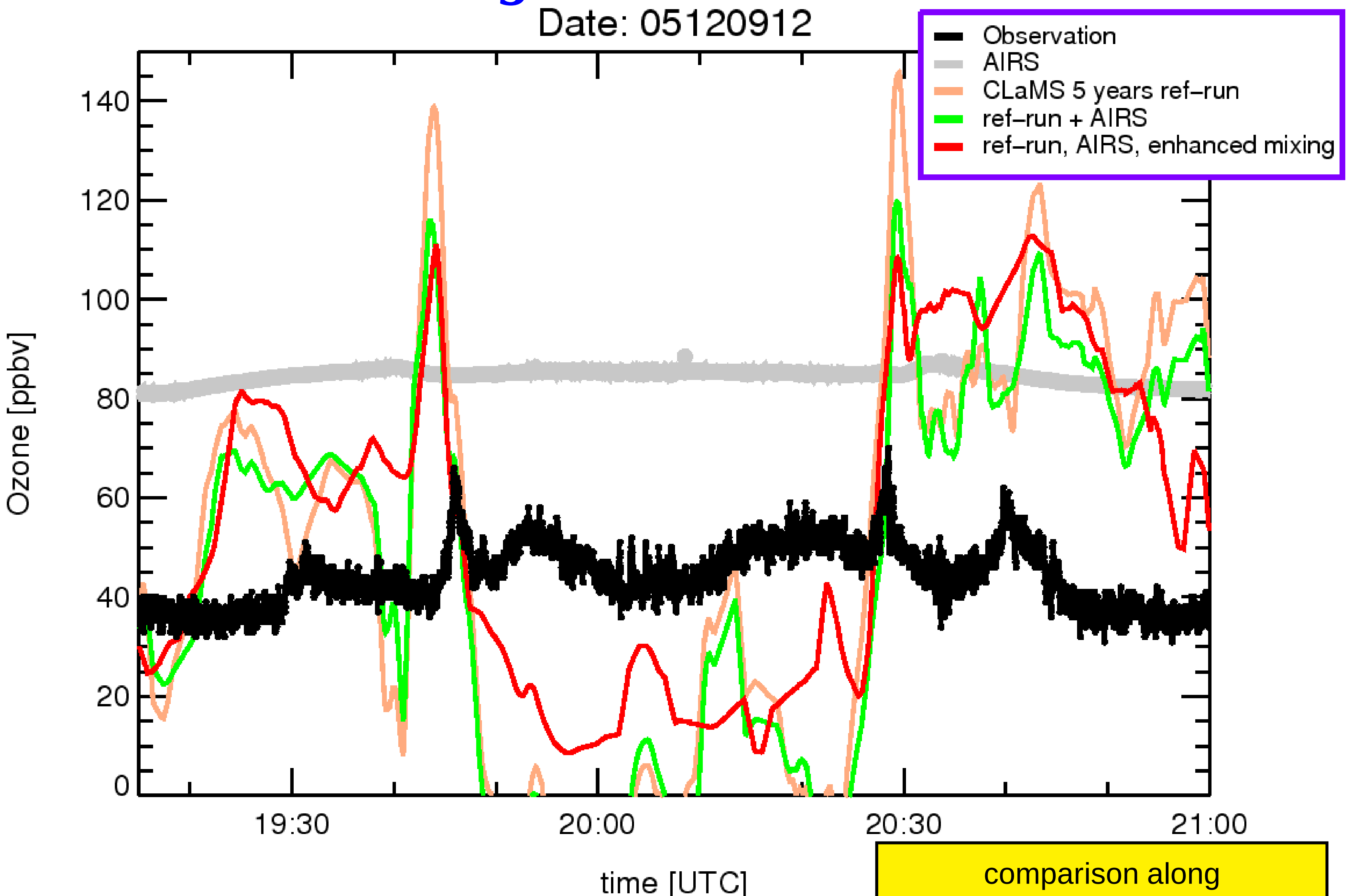
Flight an 9.12.2005



CLaMS + AIRS

Flight an 9.12.2005



comparison along
the flight track

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Conclusions

- START-05

  1. Multi-annual (5 years) CLaMS runs (100 km hor. resol.) reproduce the observed variability of O_3.
  2. Nested runs (50 km hor. resol.) with enhanced (CLaMS) mixing improve such simulations
  3. CLaMS overestimates the lifetime of stratospheric intrusions in the troposphere:
     (-) due to neglected ozone destruction cycles ?
     (-) due to wrong vertical velocities (ECMWF versus radiation) ?
     (-) due to incomplete (CLaMS) mixing ?

- START-08 - some ideas...

  1. CLaMS driven by GFS (NCEP) winds (heating/cooling rates from NCEP data ?)
  2. "nearly real time", high resolution (50 km or higher, nested mode) simulations during the campaign with O_3, CO, CO_2, H_2O, age spectrum (no forecast mode !).
  3. Improvement of CLaMS mixing,
     e.g. driven by thermal stability, N-Brunt-Väisälä frequency, Ri-gradient Richardson number (Jaeger and Sprenger, JGR, 2007).
  4. Influence of double tropopause on mixing (Randel et al. JGR, 2007)
  5. Seasonality of transport versus jet strength (polar and subtropical)