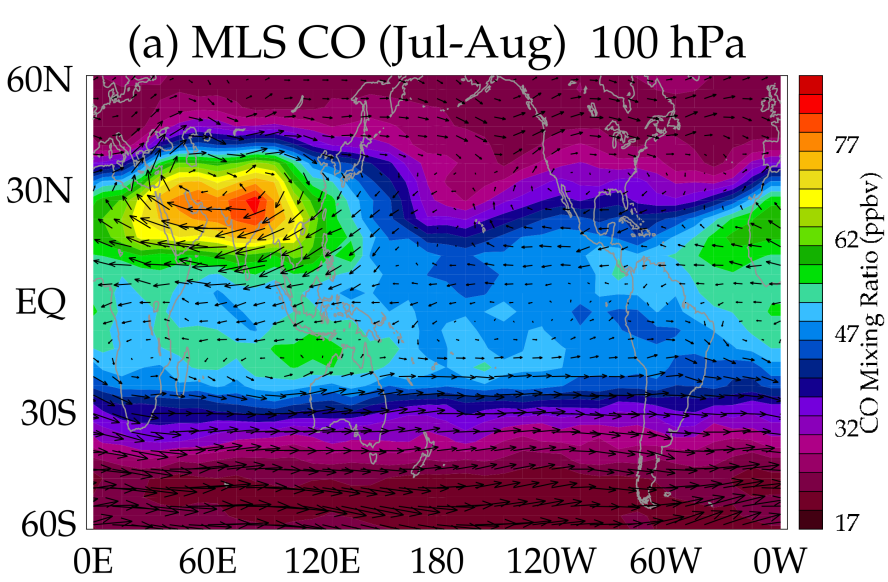
A PV-based determination of the transport barrier in the Asian summer monsoon anticyclone

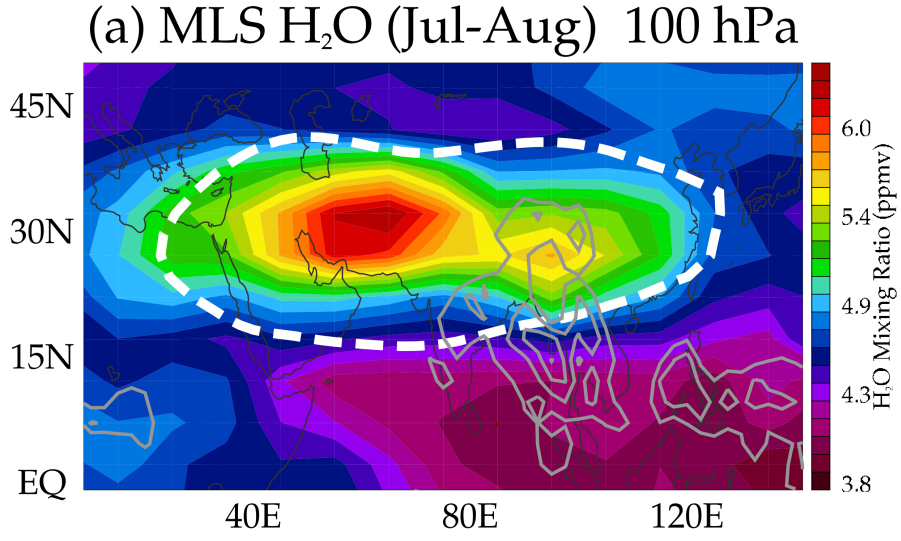
Felix Ploeger, C. Gottschling, S. Griessbach J.-U. Grooß, G. Günther, P. Konopka, R. Müller, M. Riese, F. Stroh, M. Tao, J. Ungermann, B. Vogel, M. von Hobe

Ploeger et al., 2015, ACP, 15, 13145–13159, doi: 10.5194/acp-15-13145-2015

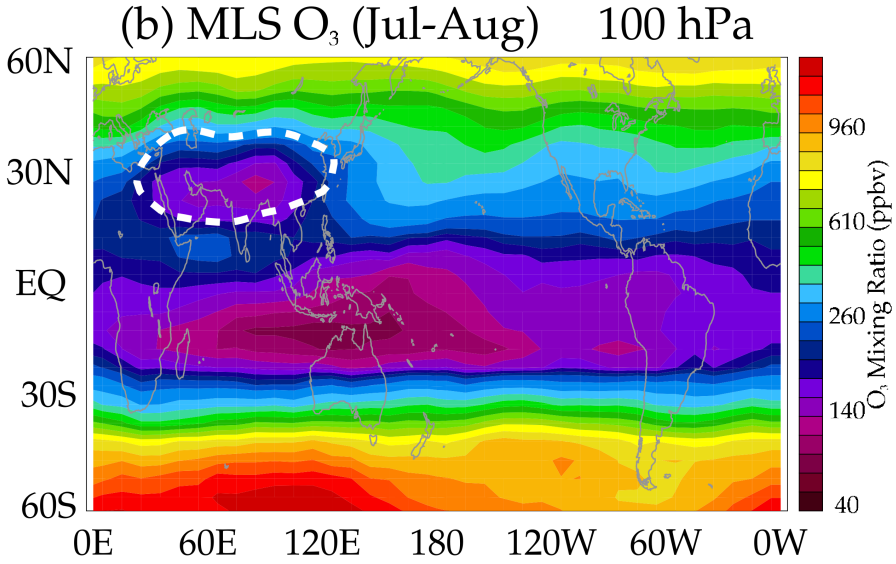
Monsoon-workshop, Boulder

Motivation: Confinement in anticyclone?





[Park et al.,2007]

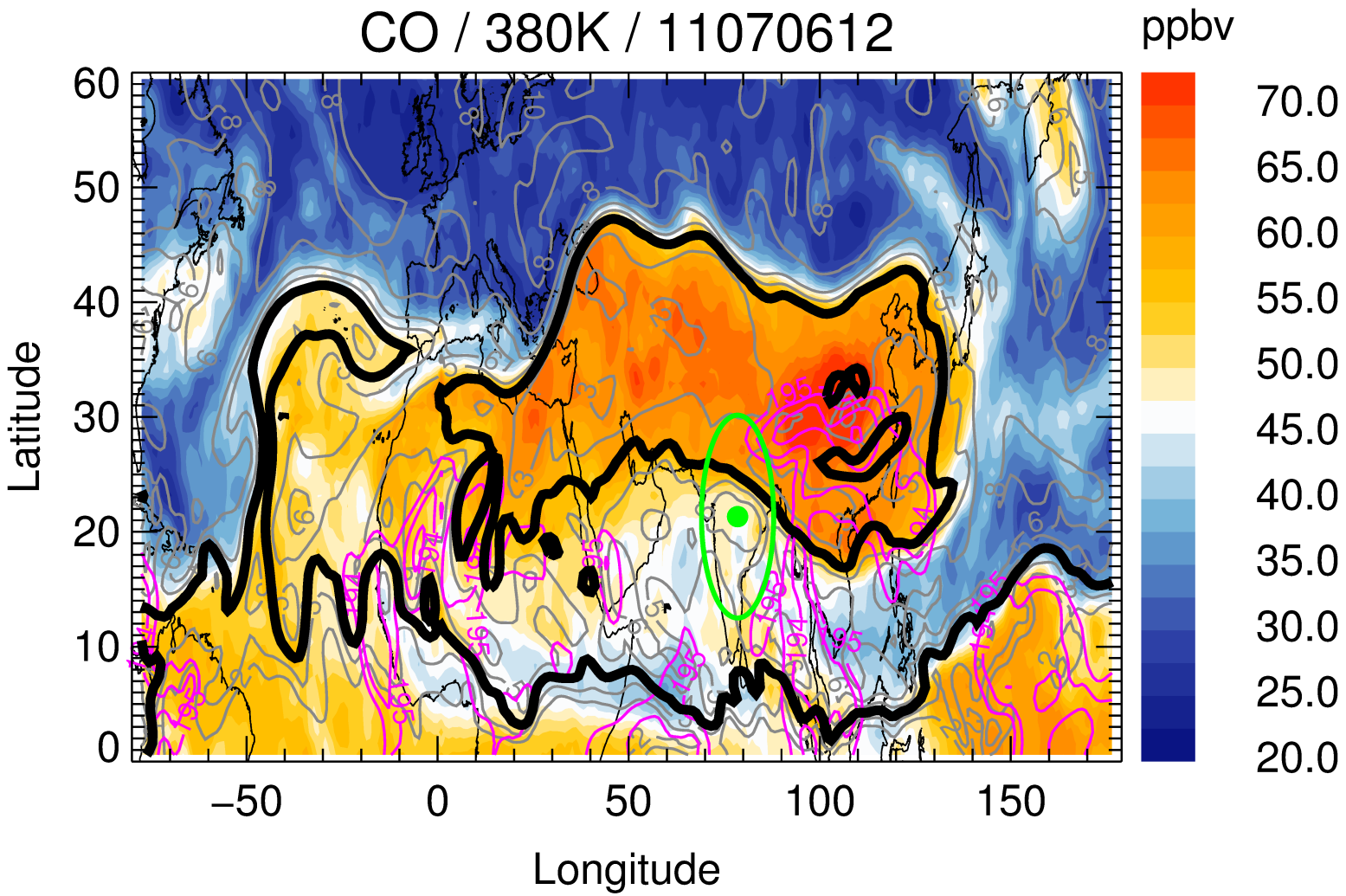


- confinement of tropospheric trace gases (CO, H_2O, ...) inside anticyclone

How well is confinement:

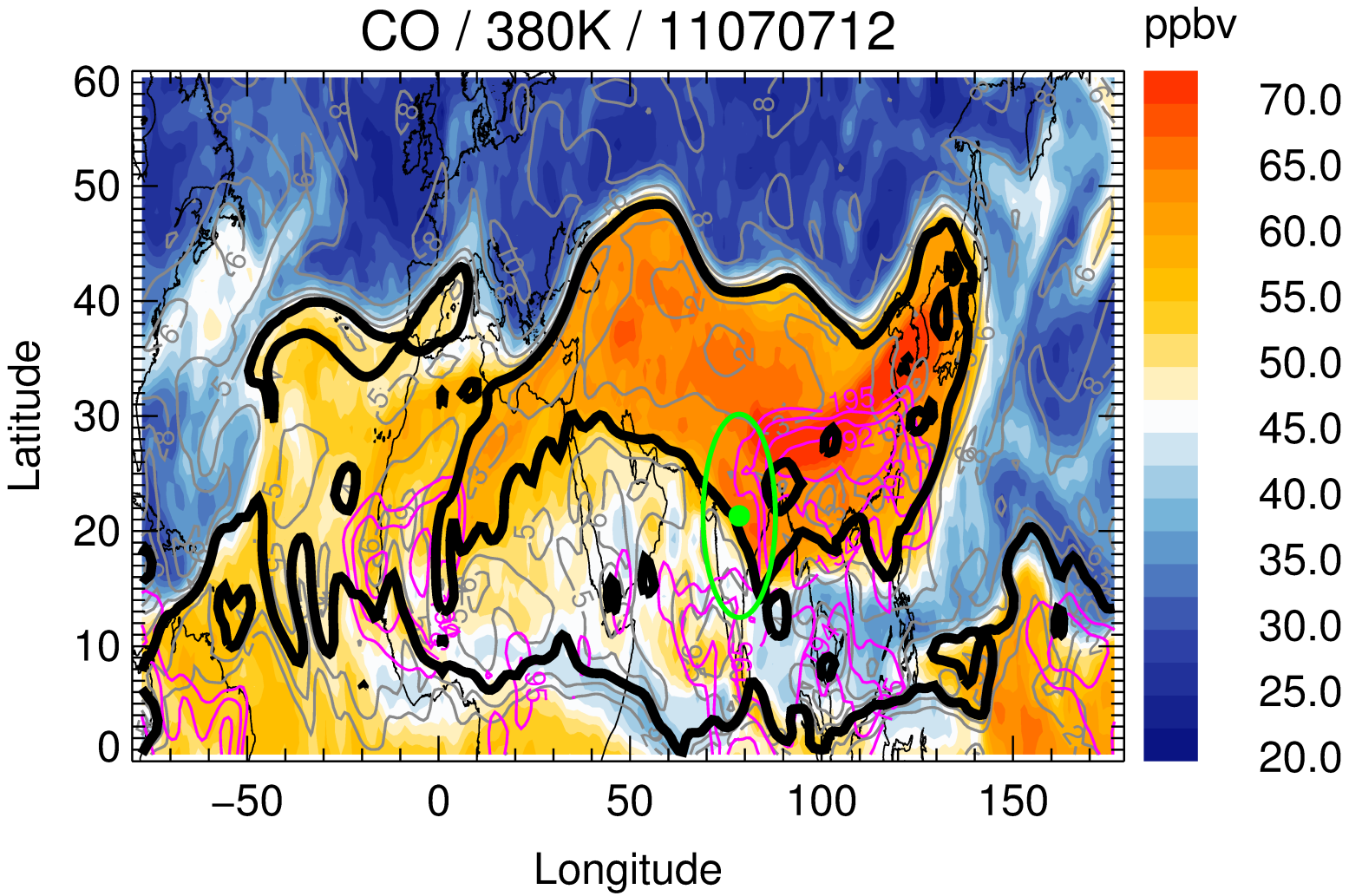
⇒ find transport barrier in Asian monsoon?

Motivation: Confinement in anticyclone?



- CO in monsoon anticyclone (380 K) from CLaMS follows PV

Motivation: Confinement in anticyclone?



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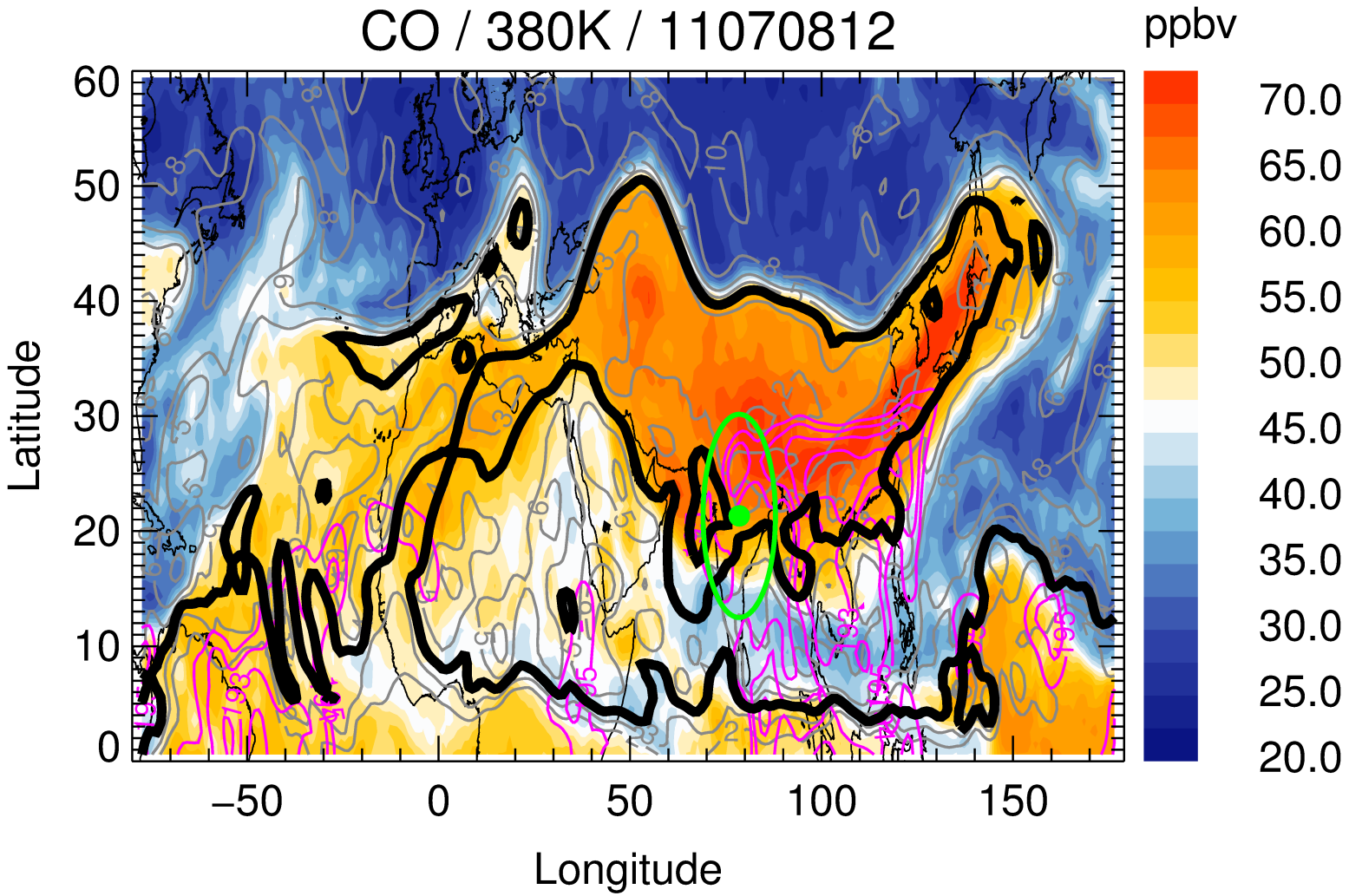

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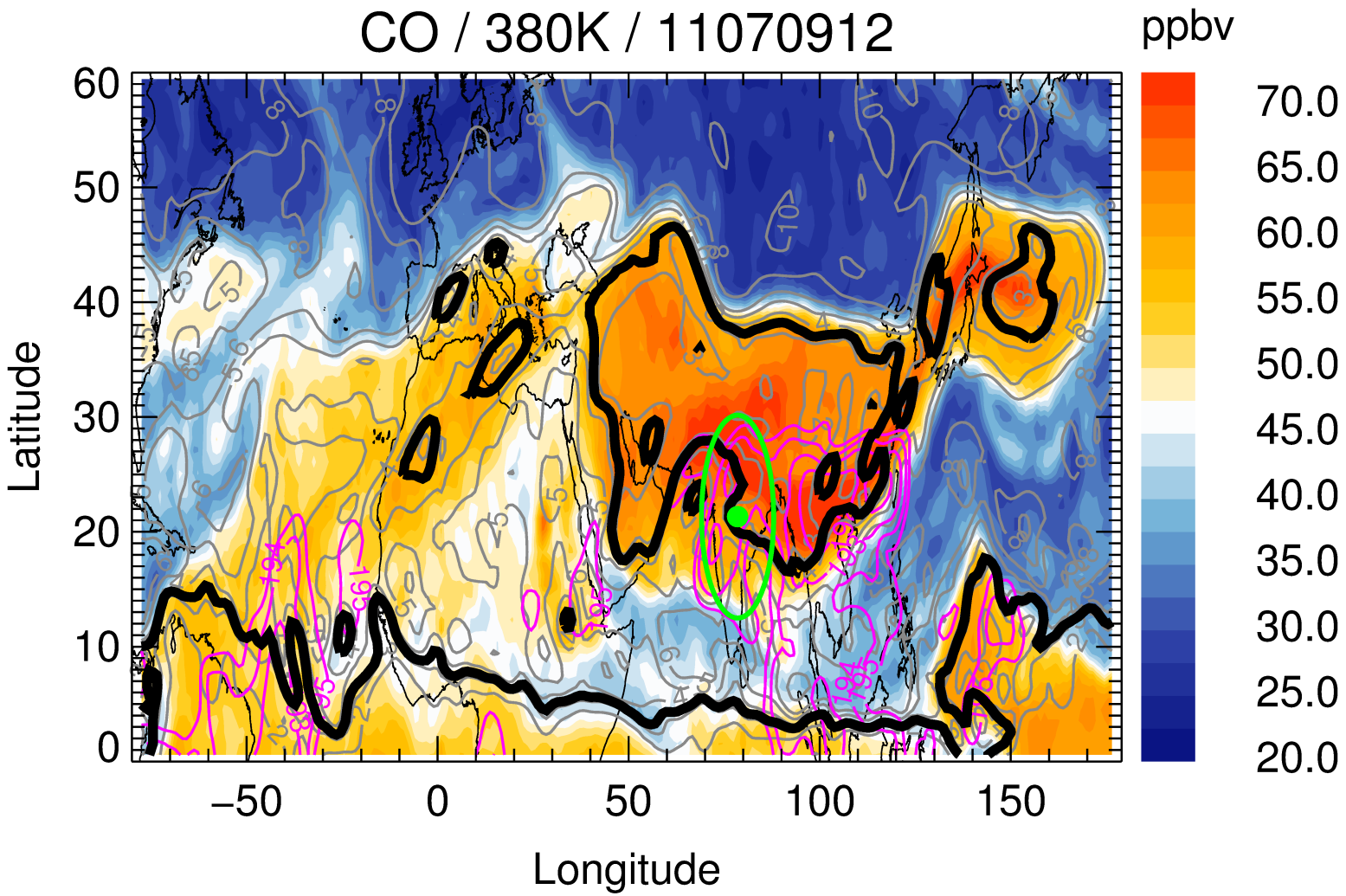

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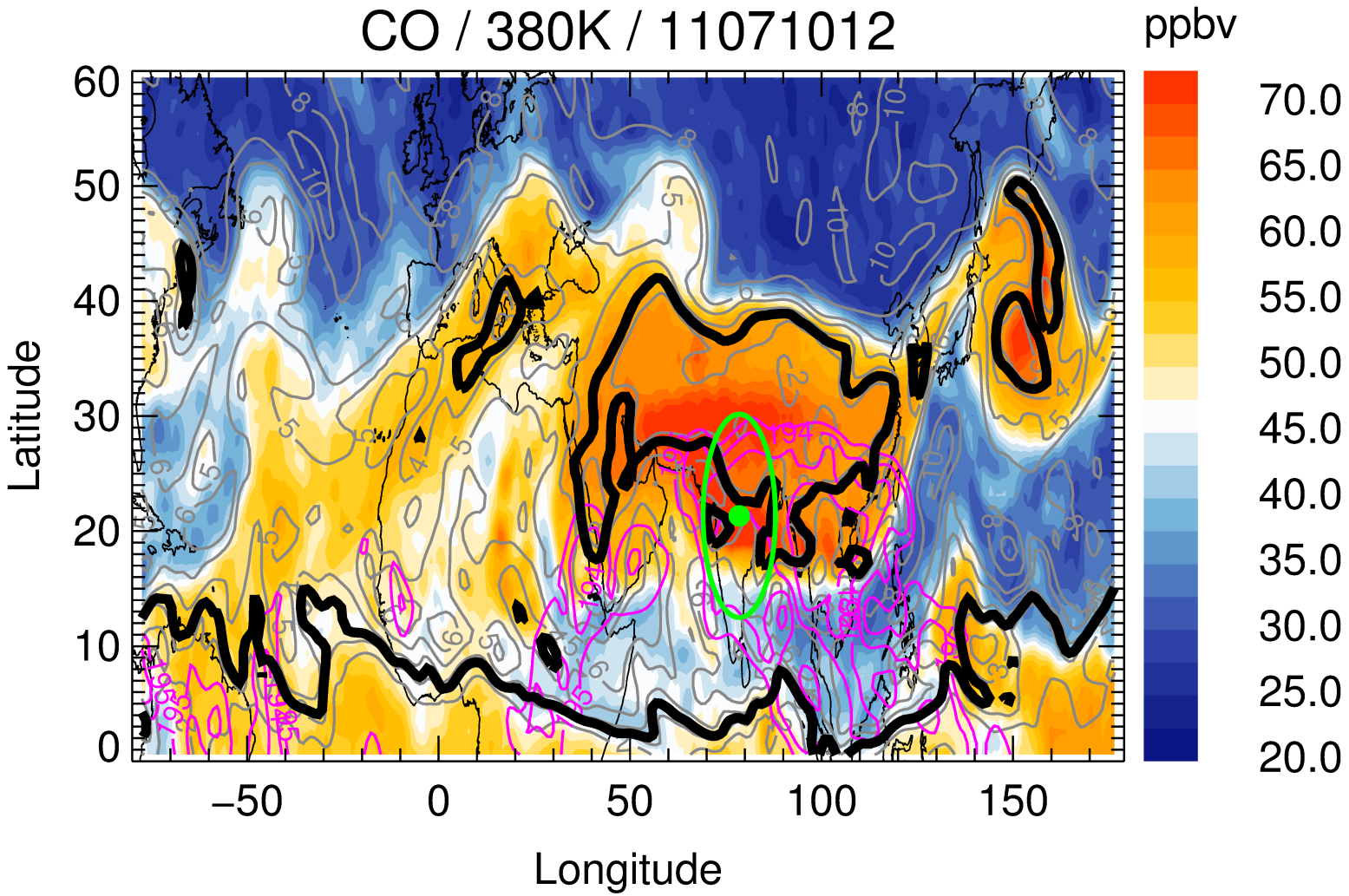

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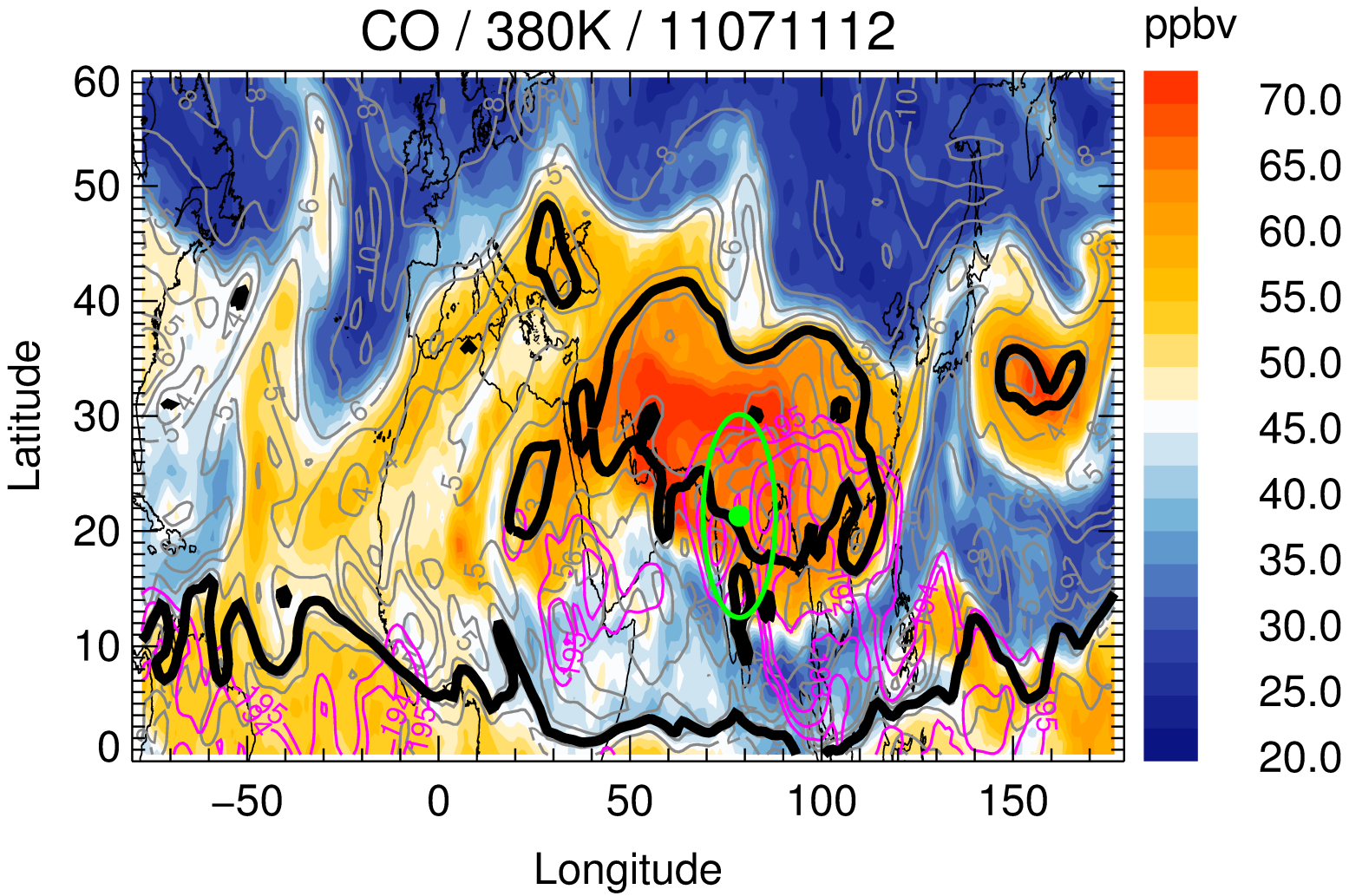

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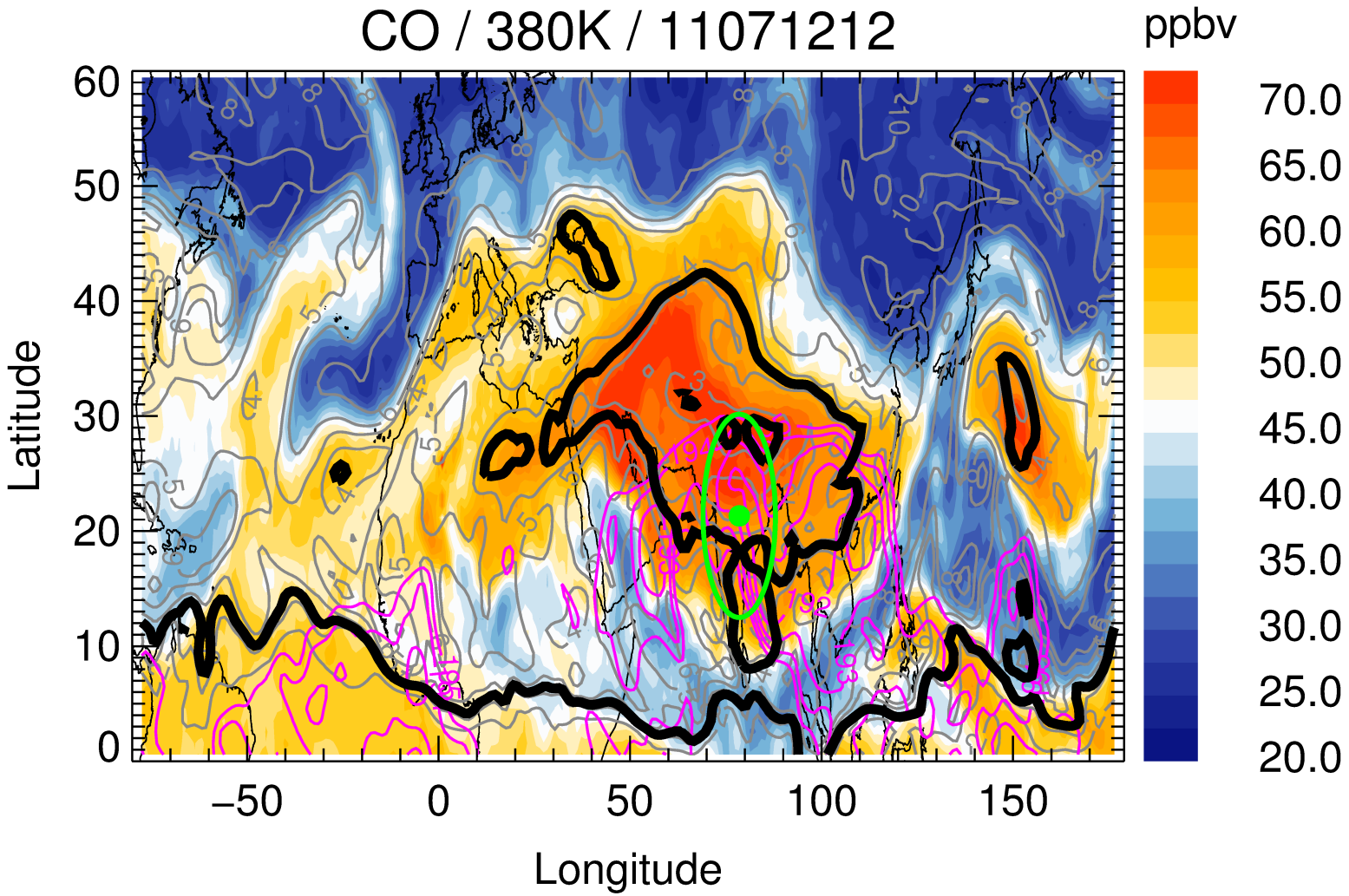
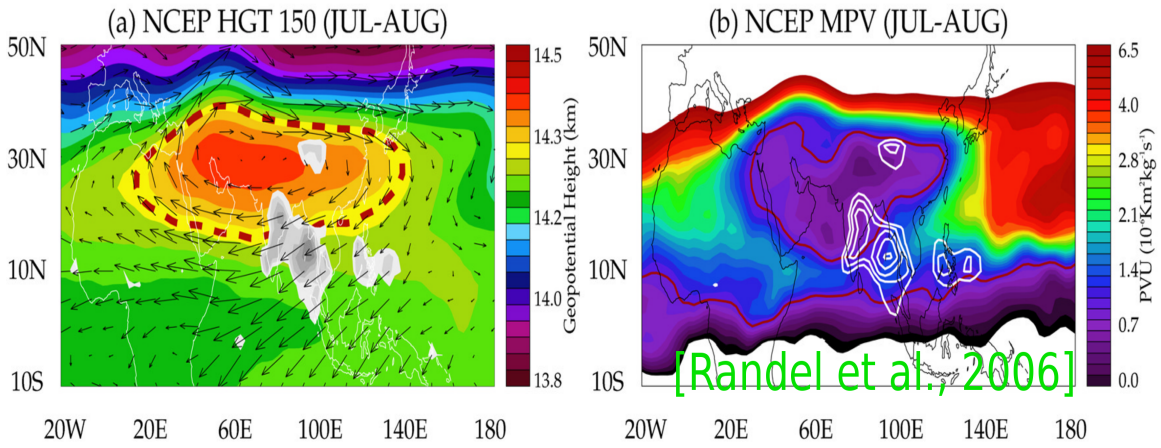
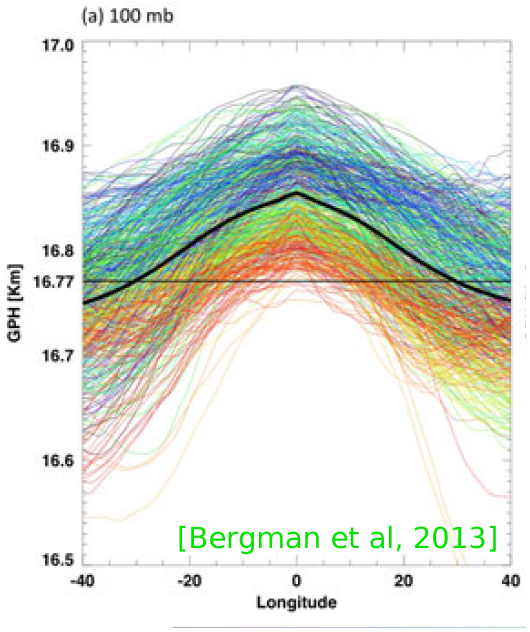


- eddy-shedding to the east **(see talk by B. Vogel, Thursday)**

Various criteria for confinement/barrier

- geopotential GPH $=$ 14.320 km on 150 hPa [Randel et al.,2006]
- MPV $=$ 1.5 PVU on 360 K [Randel et al.,2006]
- GPH $=$ 12.52/16.77 km at 200/100 hPa [Bergman et al.,2013]
- ...





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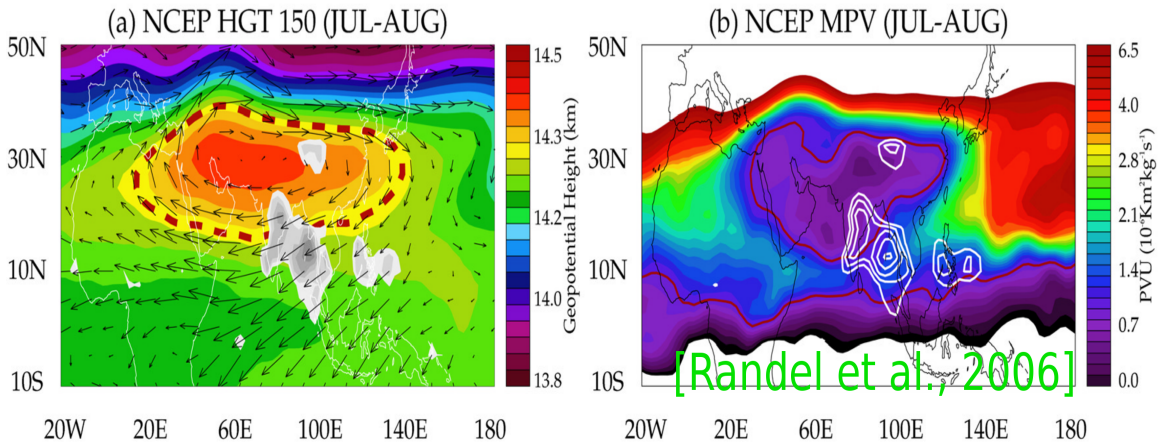
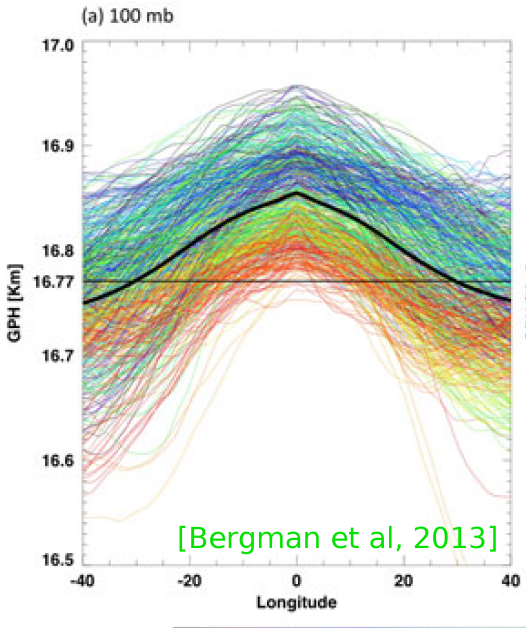




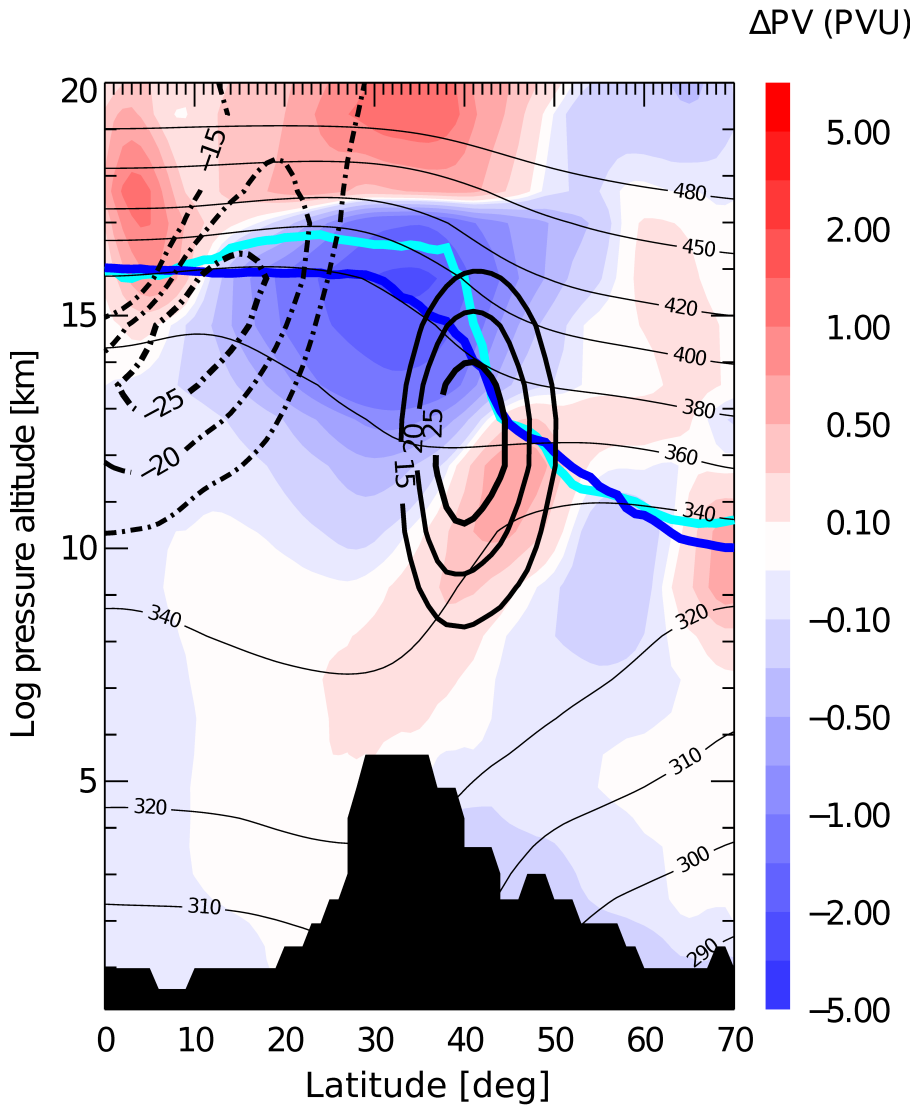
Our goal:

$\Rightarrow$ universal criterion for transport barrier in Asian monsoon!

Outline

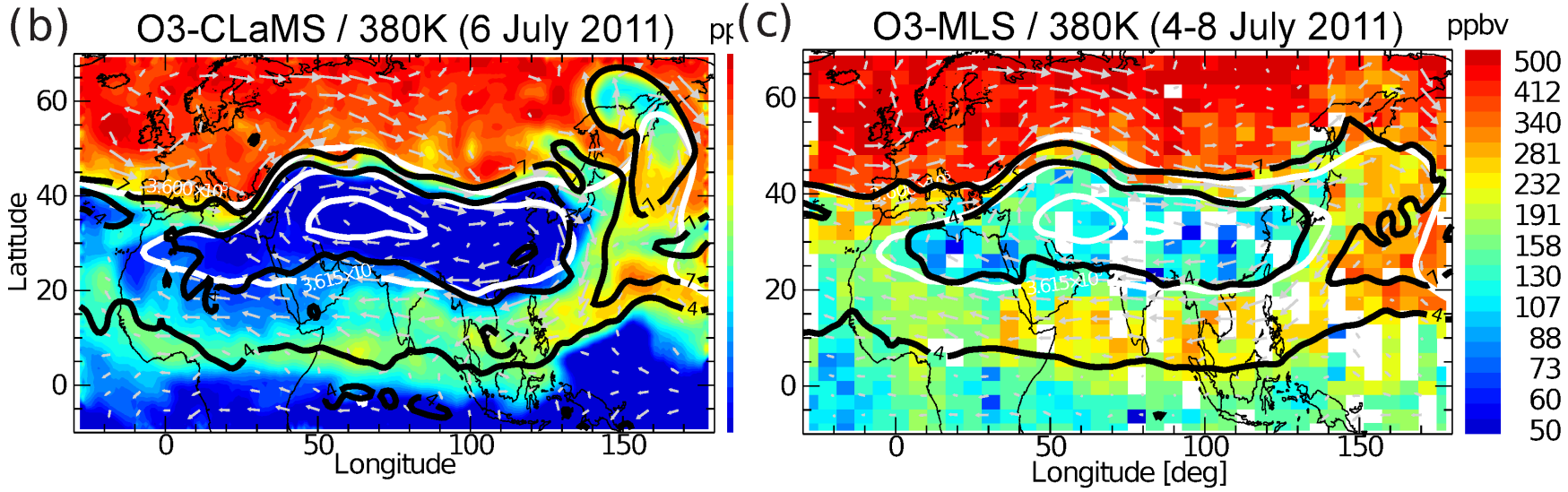
- Introduction: Asian monsoon transport
- Method:
  Localize a transport barrier in monsoon anticyclone
- Validation: Compare the transport barrier to trace gases
- Outlook: transport timescales (age spectrum)
- Conclusions & Outlook

Vertical structure of Asian monsoon



- anticyclone: negative PV anomaly, elevated tropopause, ...

O3 confinement: PV versus Geopotential



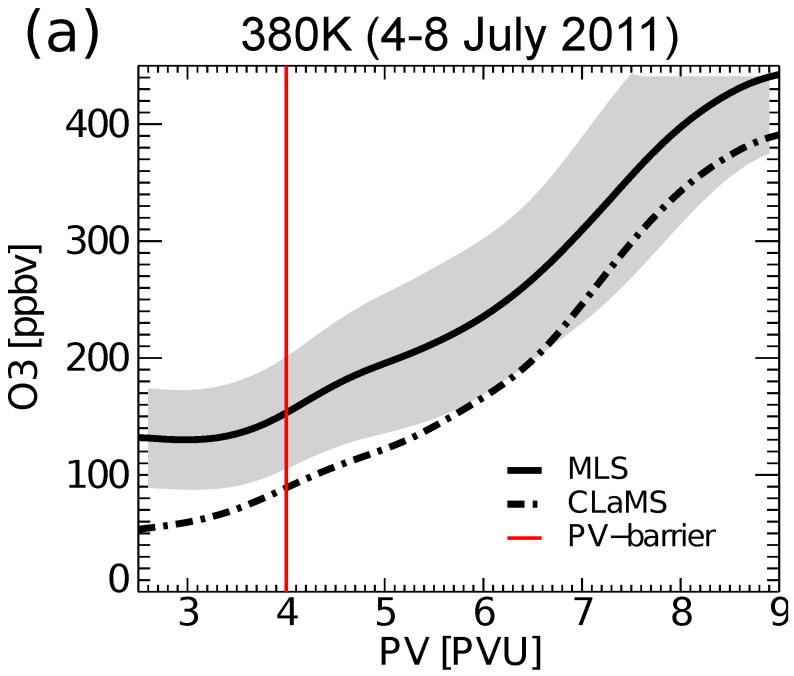
- Montgomery stream function (white) $M = c_p T + \Phi$

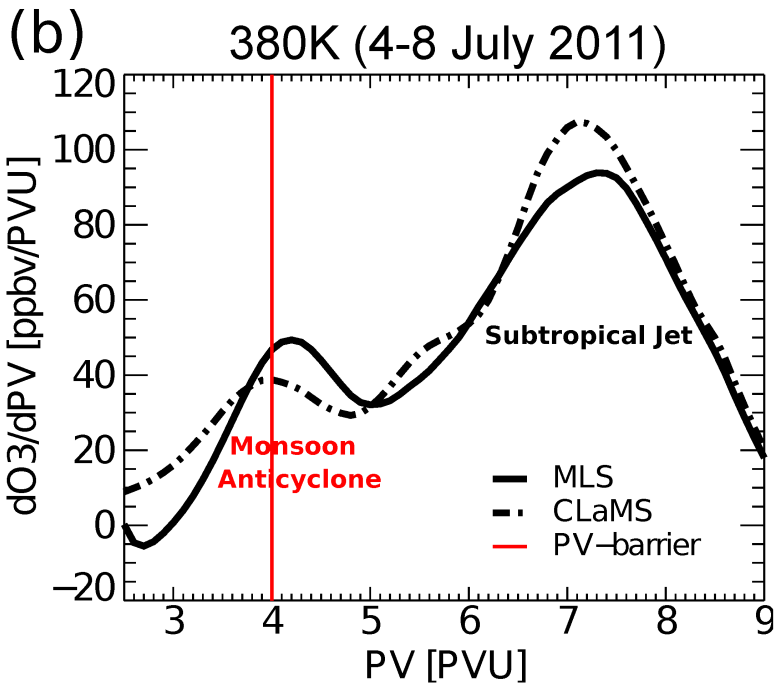
  $\Rightarrow$ compares not well with ozone

- Tracer confinement best described by PV (black)

  $\Rightarrow$ Let's map ozone versus PV...!

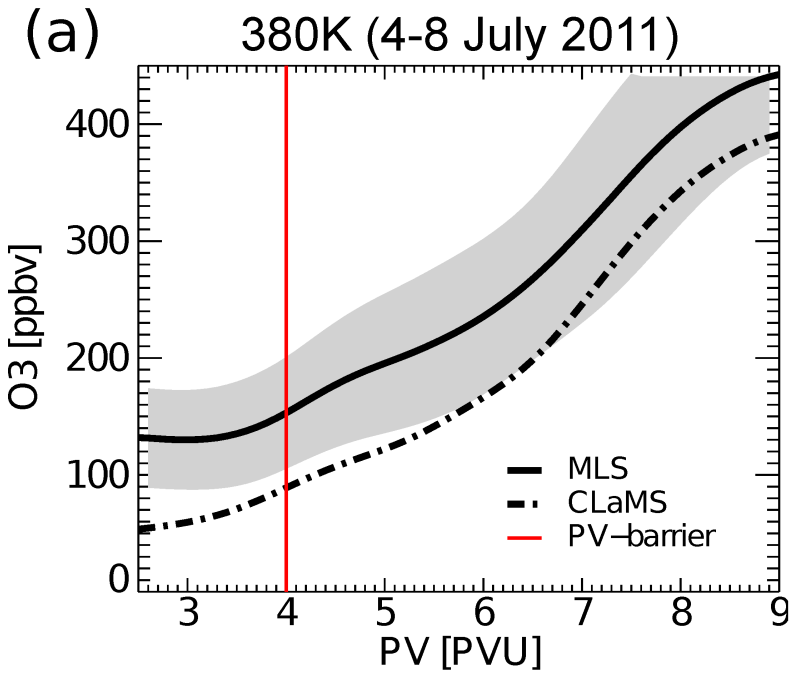
Maximum PV-gradient shows transport barrier

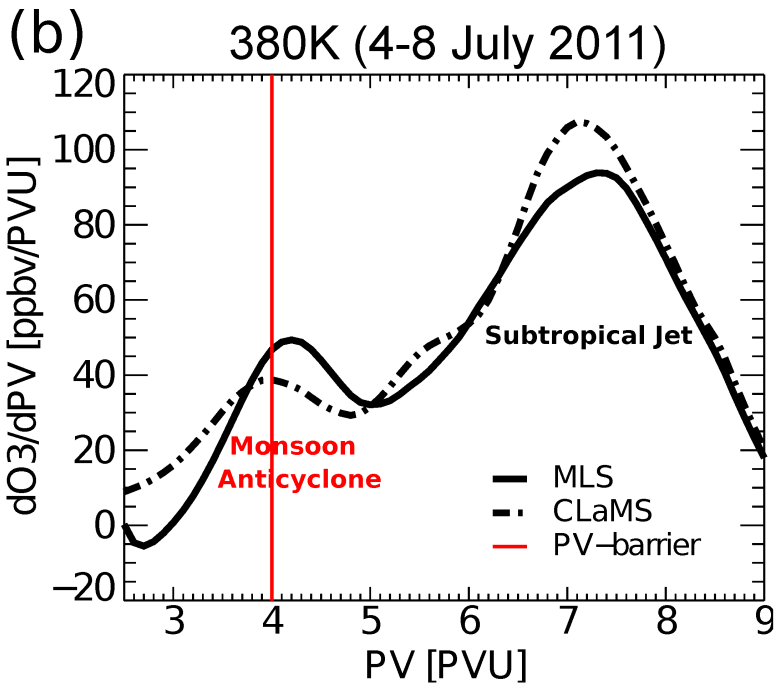




- Conserved quantity (O_3, PV, ...):
  enhanced gradient $\Rightarrow$ transport barrier
- Secondary O_3-maximum: Anticyclone barrier!

Maximum PV-gradient shows transport barrier



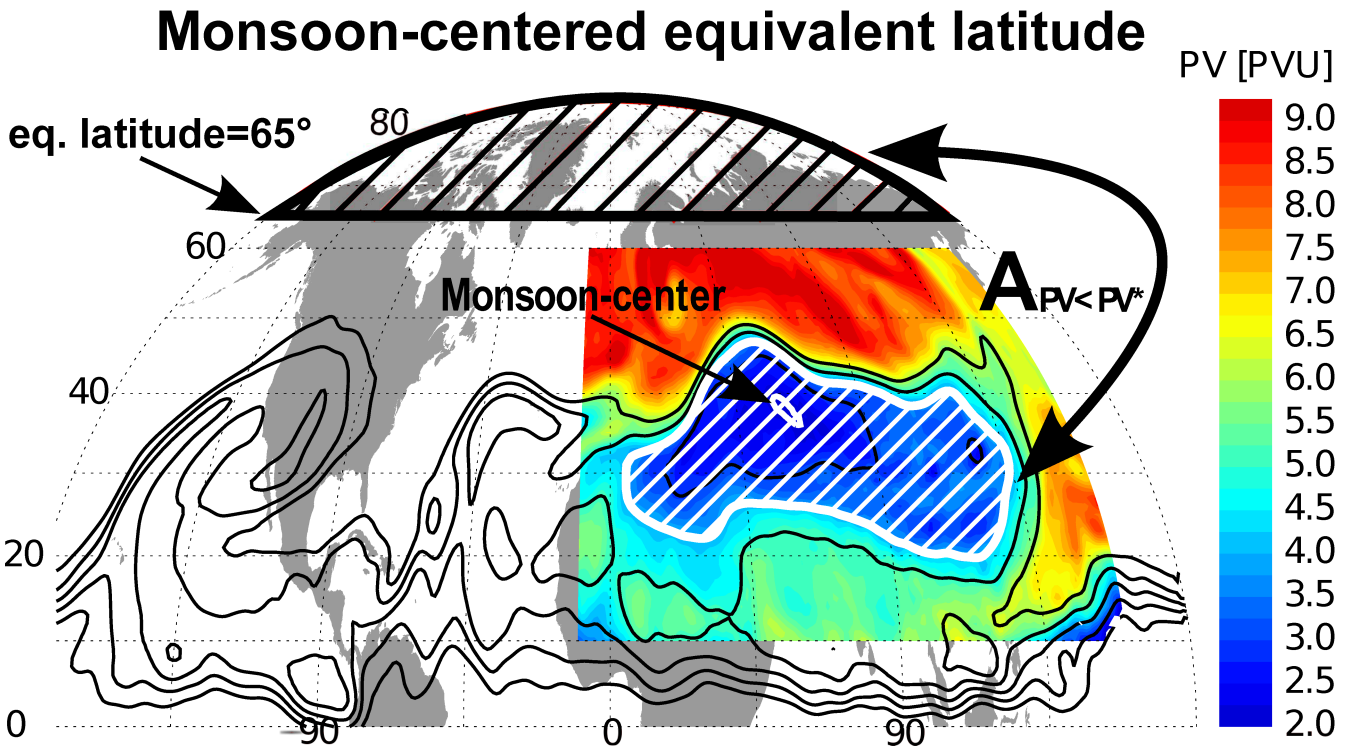


- Conserved quantity (O_3, PV, ...):
  enhanced gradient $\Rightarrow$ transport barrier
- Secondary O_3-maximum: Anticyclone barrier!

Method to estimate barrier:

$\Rightarrow$ follow Nash–criterion for polar vortex
& search PV-gradient maximum

Method: Transport barrier localization



1) Select monsoon region:

$$10^\circ\mathrm{N} \leq \phi \leq 60^\circ\mathrm{N} \text{ and } -10^\circ\mathrm{E} \leq \lambda \leq 160^\circ\mathrm{E}$$

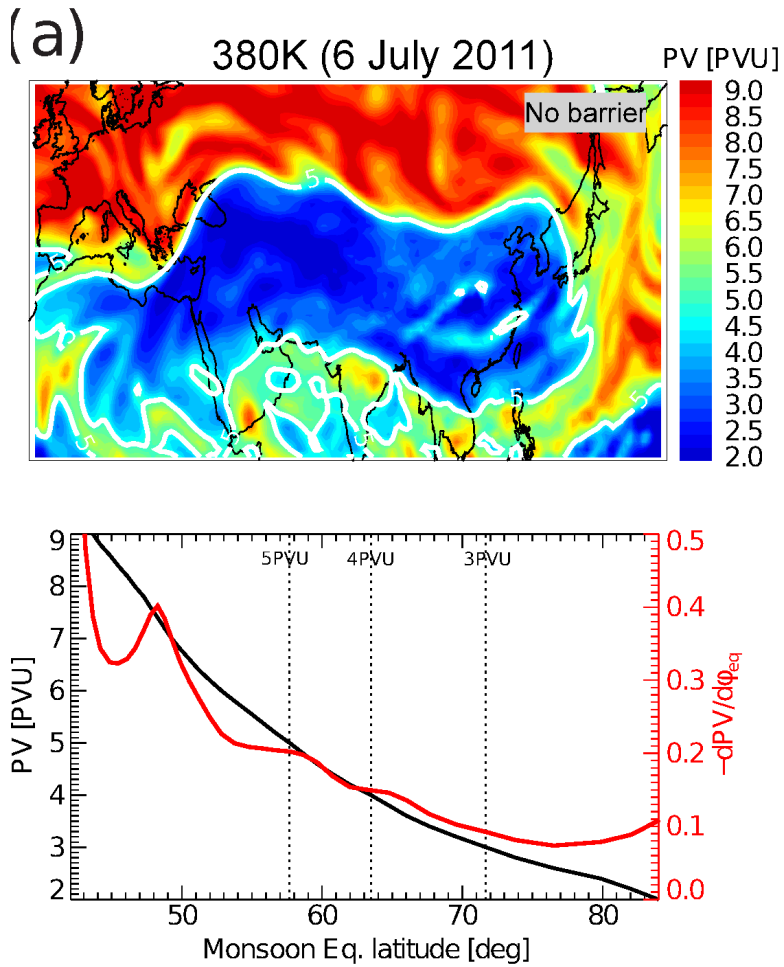
2) Define monsoon centered equivalent latitude:

$$A = 2\pi r_E^2 (1 - \sin \phi_{\mathrm{eq}})$$

3) PV as function of equiv. latitude: PV(ϕ_{eq})

Method: Search PV-gradient maximum

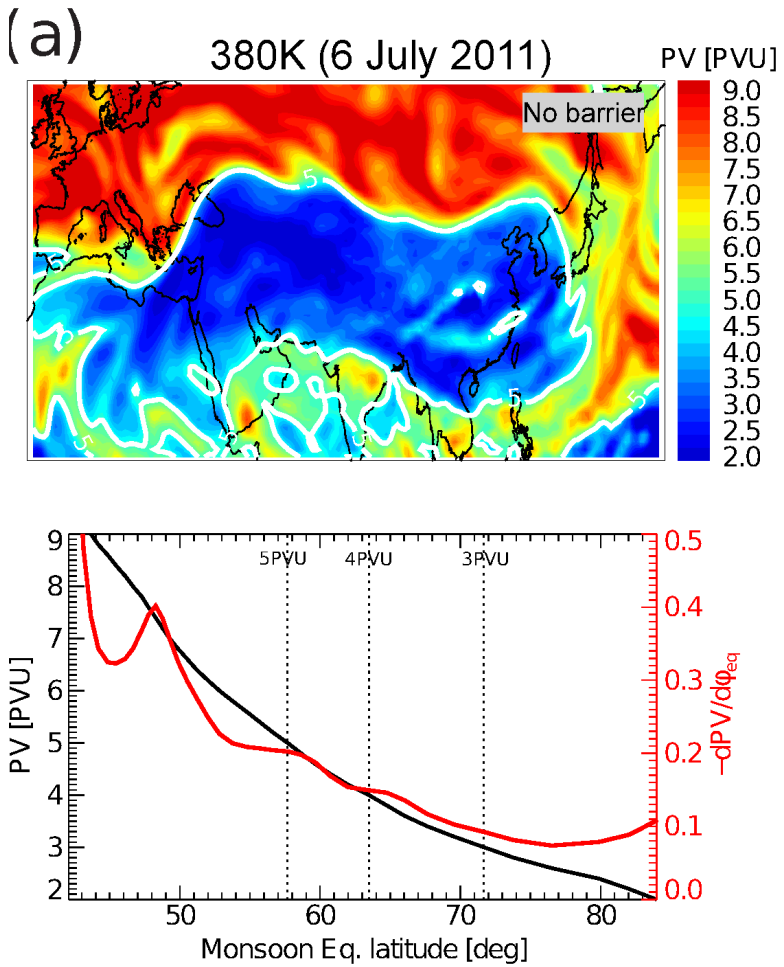
instantaneous



- no maximum in PV-gradient

Method: Search PV-gradient maximum

instantaneous



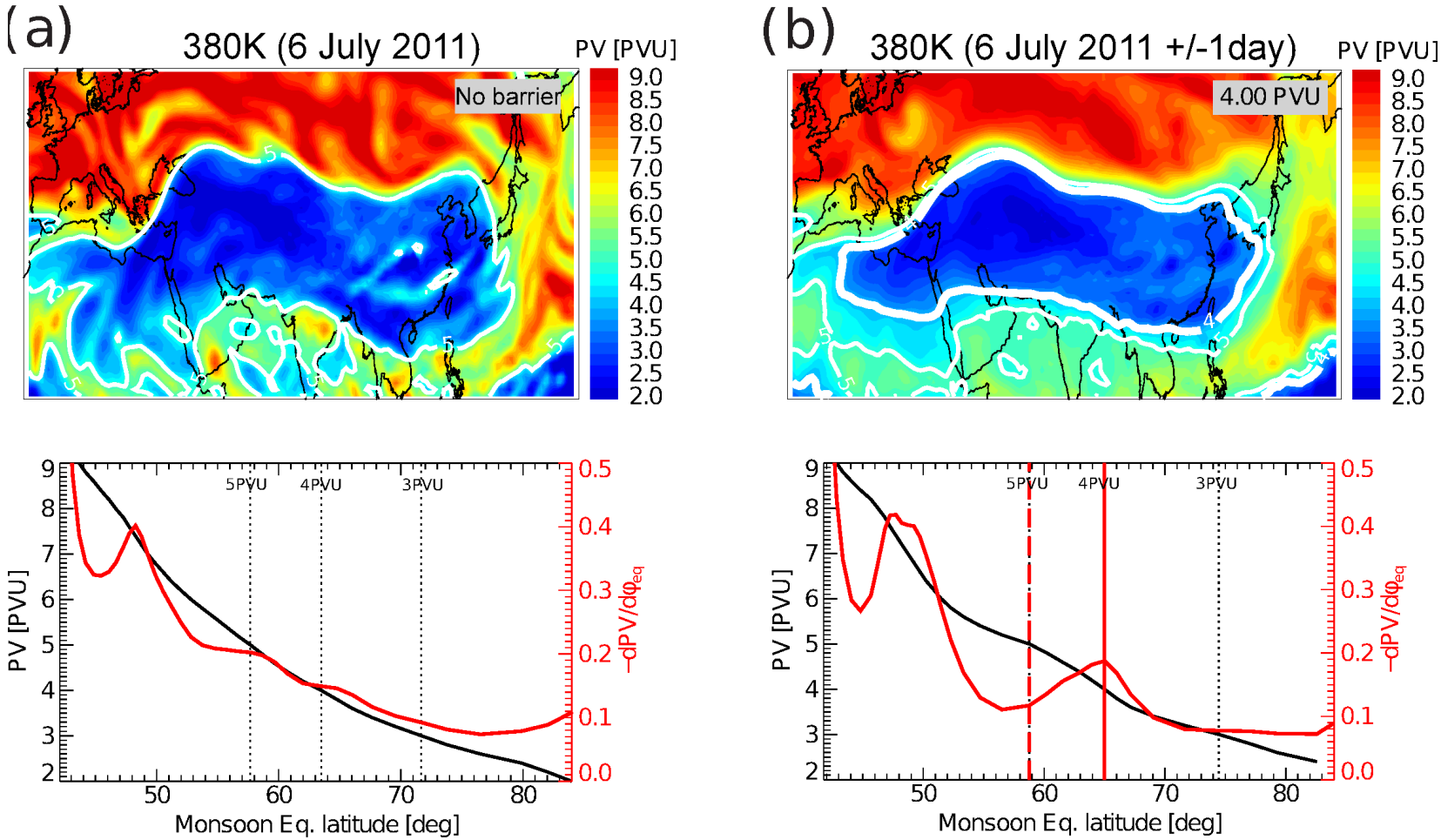
...thinking...

- no maximum in PV-gradient

Method: Search PV-gradient maximum

instantaneous

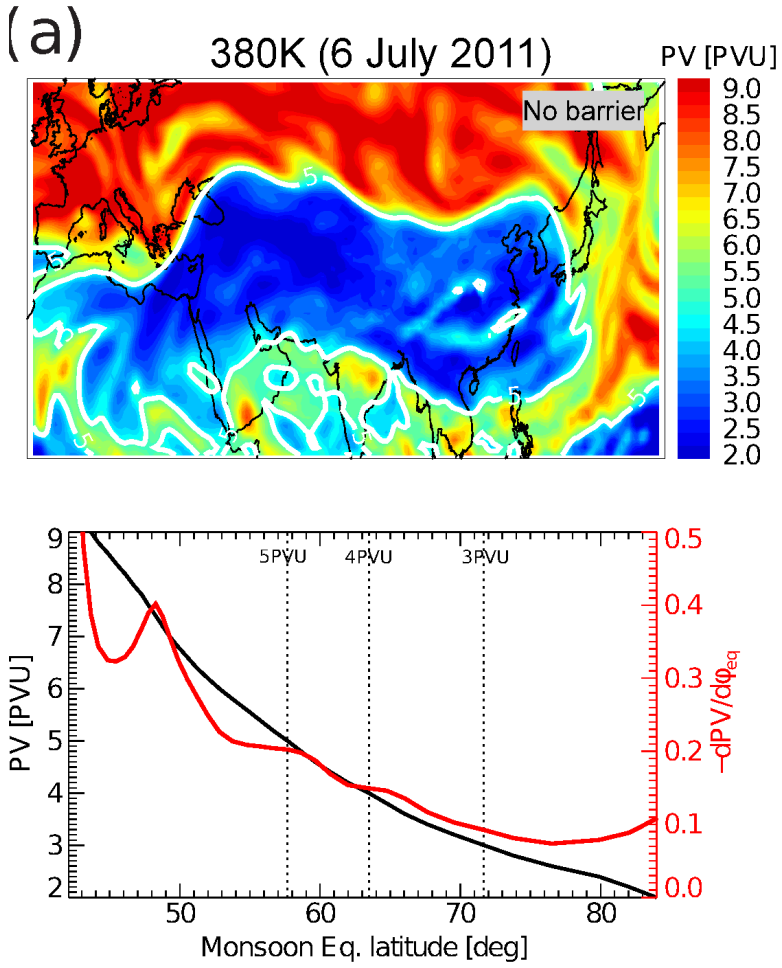
3-day average



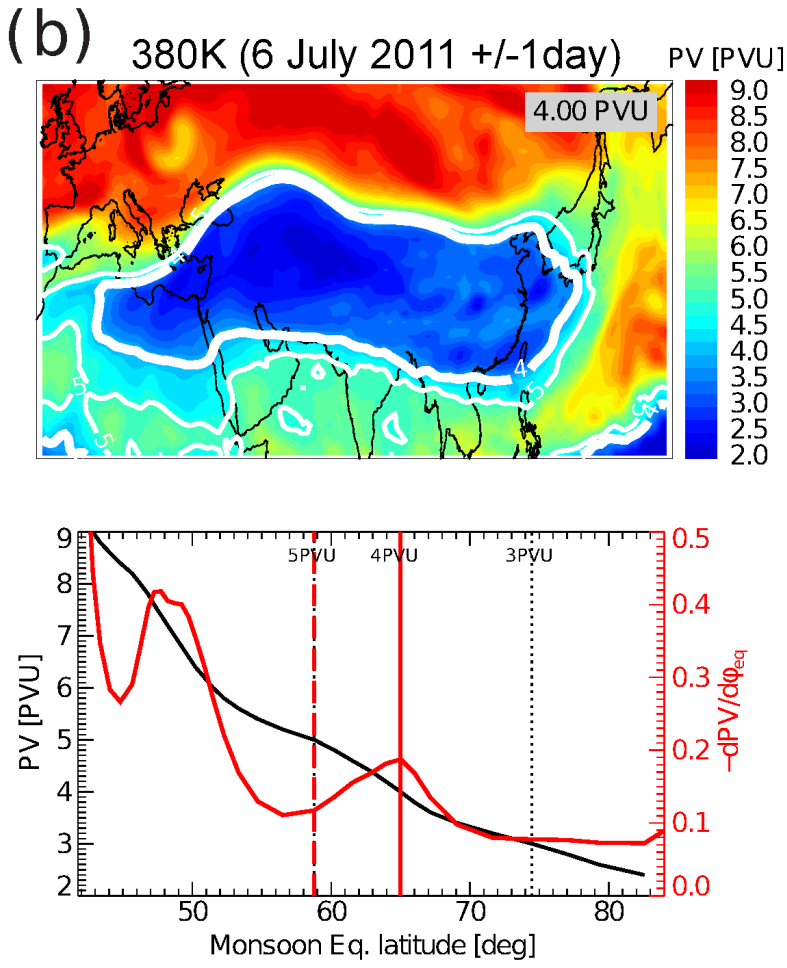
- no maximum in PV-gradient
- maximum in PV-gradient !!!

Method: Search PV-gradient maximum

instantaneous



3-day average

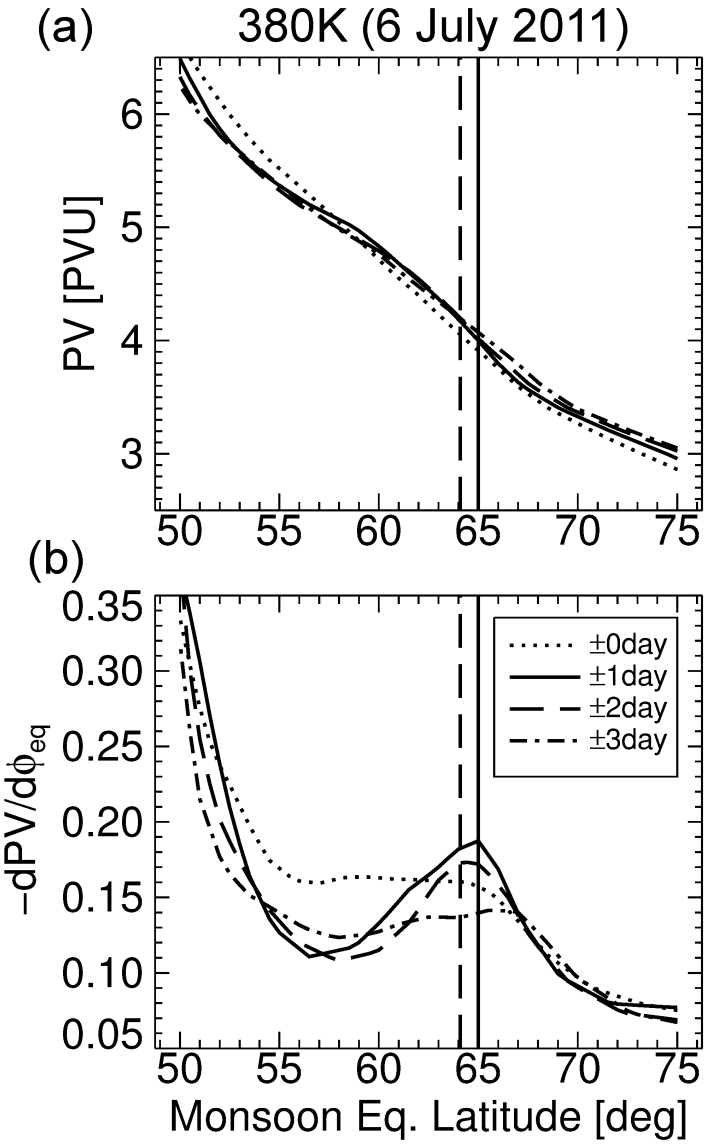


Time averaging:

⇒ smoothes PV variability!

maximum in PV-gradient !!!

Method: Time-averaging



- average smoothes variability:

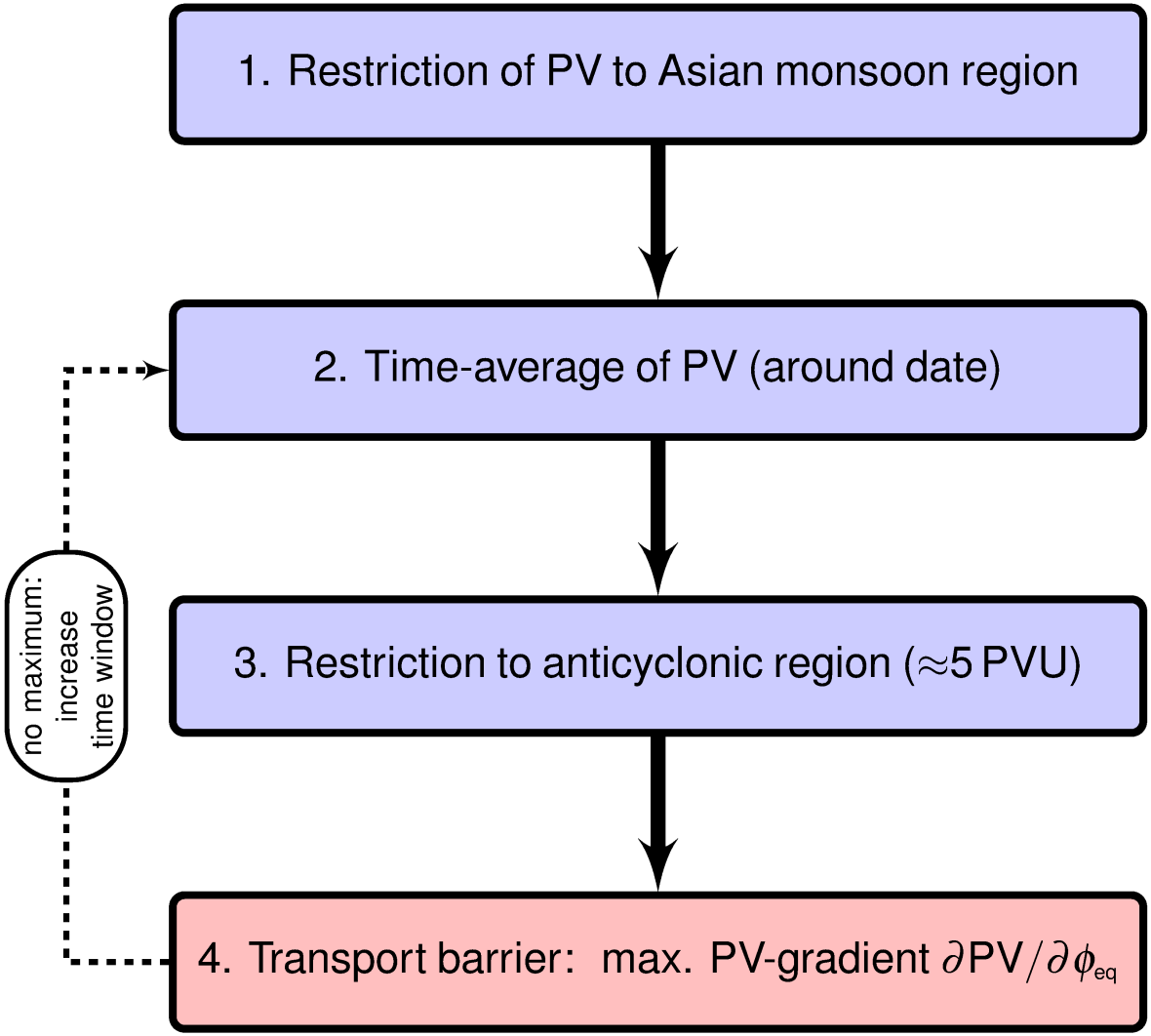
  ⇒ maximum clearer

- period too long:

  ⇒ different dyn. situations

  ⇒ optimal time-window !

Cooking Recipe: Anticyclone transport barrier



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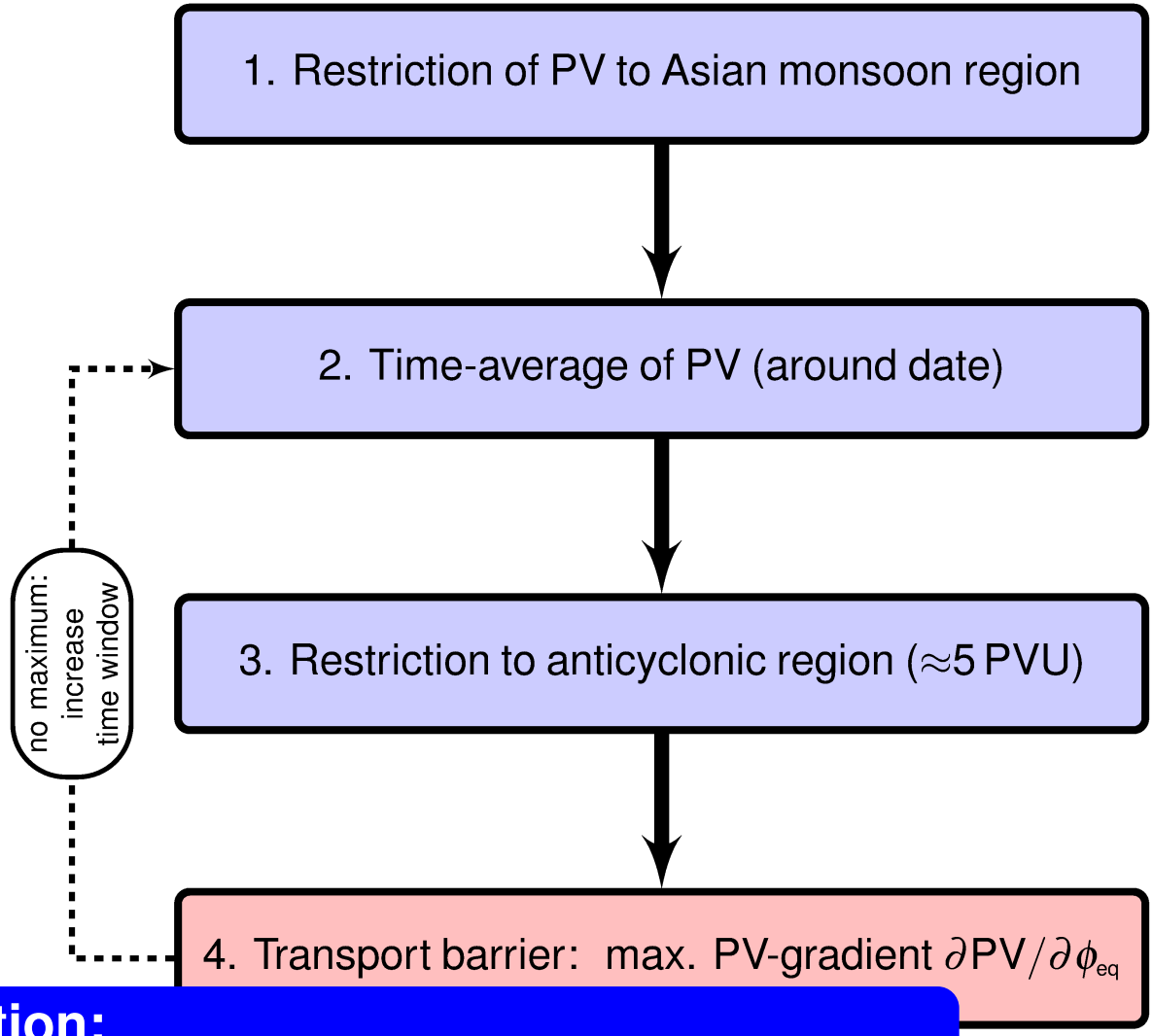
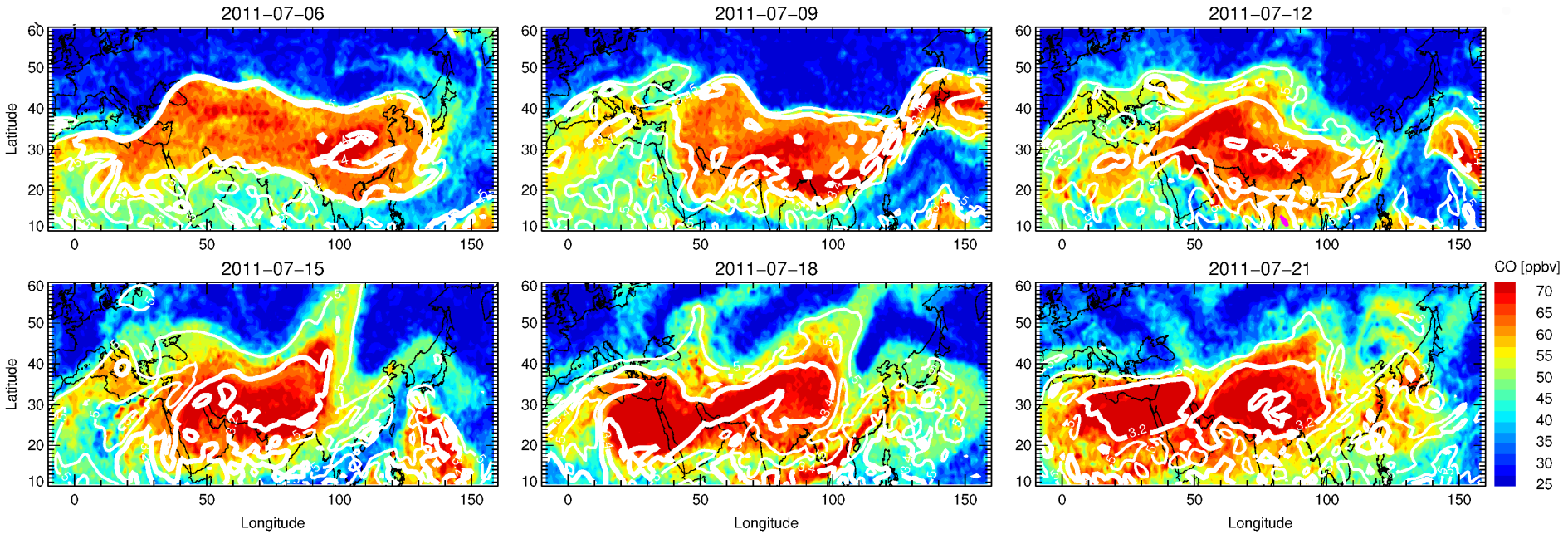


Question:

Is PV-barrier meaningful in separating air masses of different chemical properties?

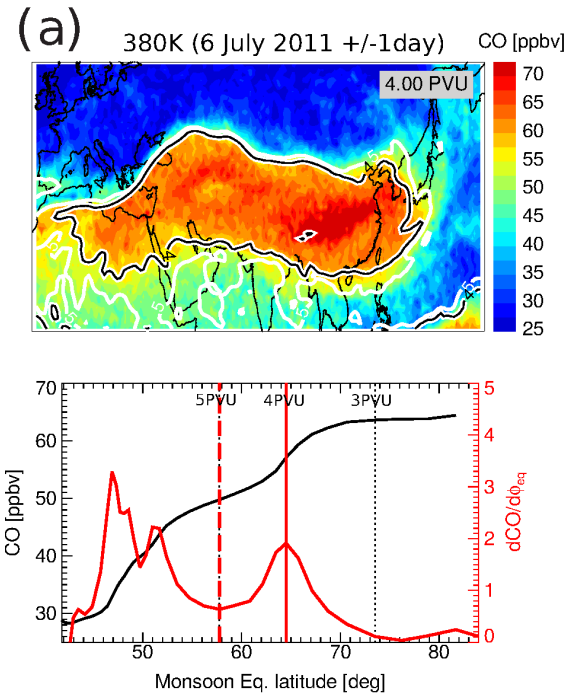
Comparison: PV-barrier vs. CO from CLaMS



- PV-barrier separates enhanced CO inside anticyclone well

Comparison: PV-barrier vs. tracer gradients

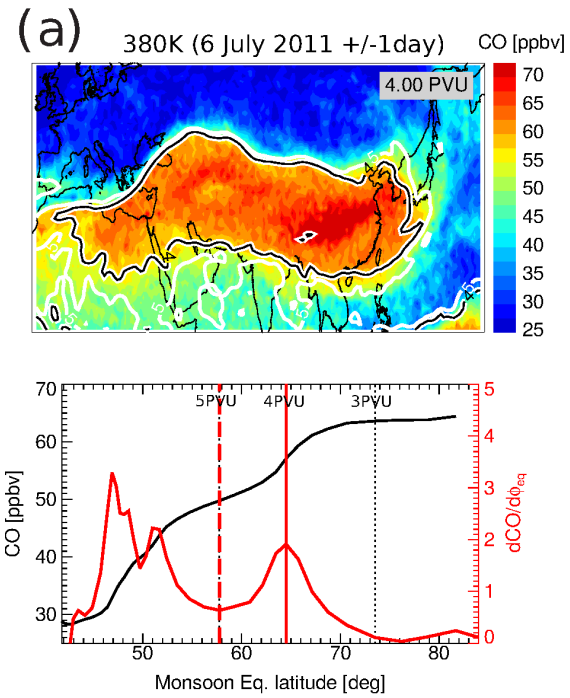
CO



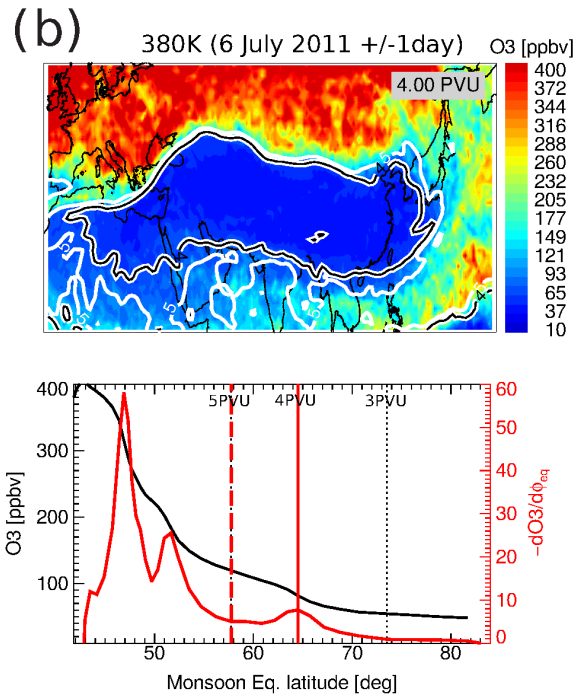
- Map tracers versus monsoon equivalent latitude
- PV-barrier agrees well with enhanced tracer gradients!

Comparison: PV-barrier vs. tracer gradients

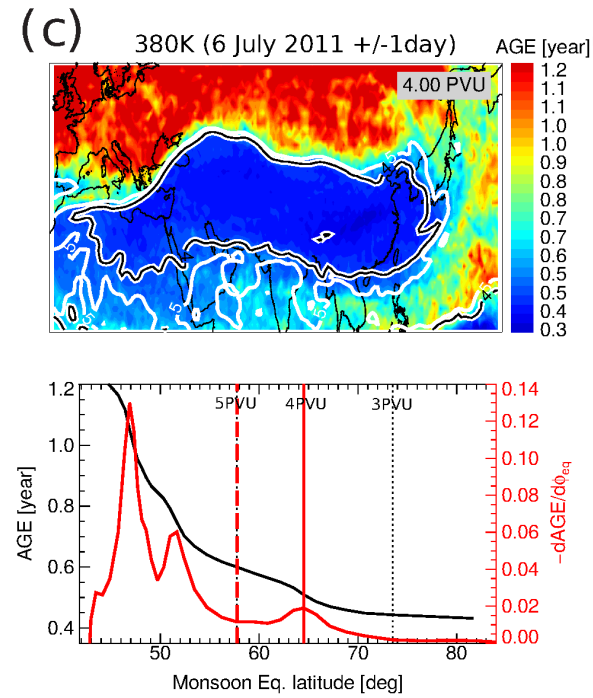
CO



O_3

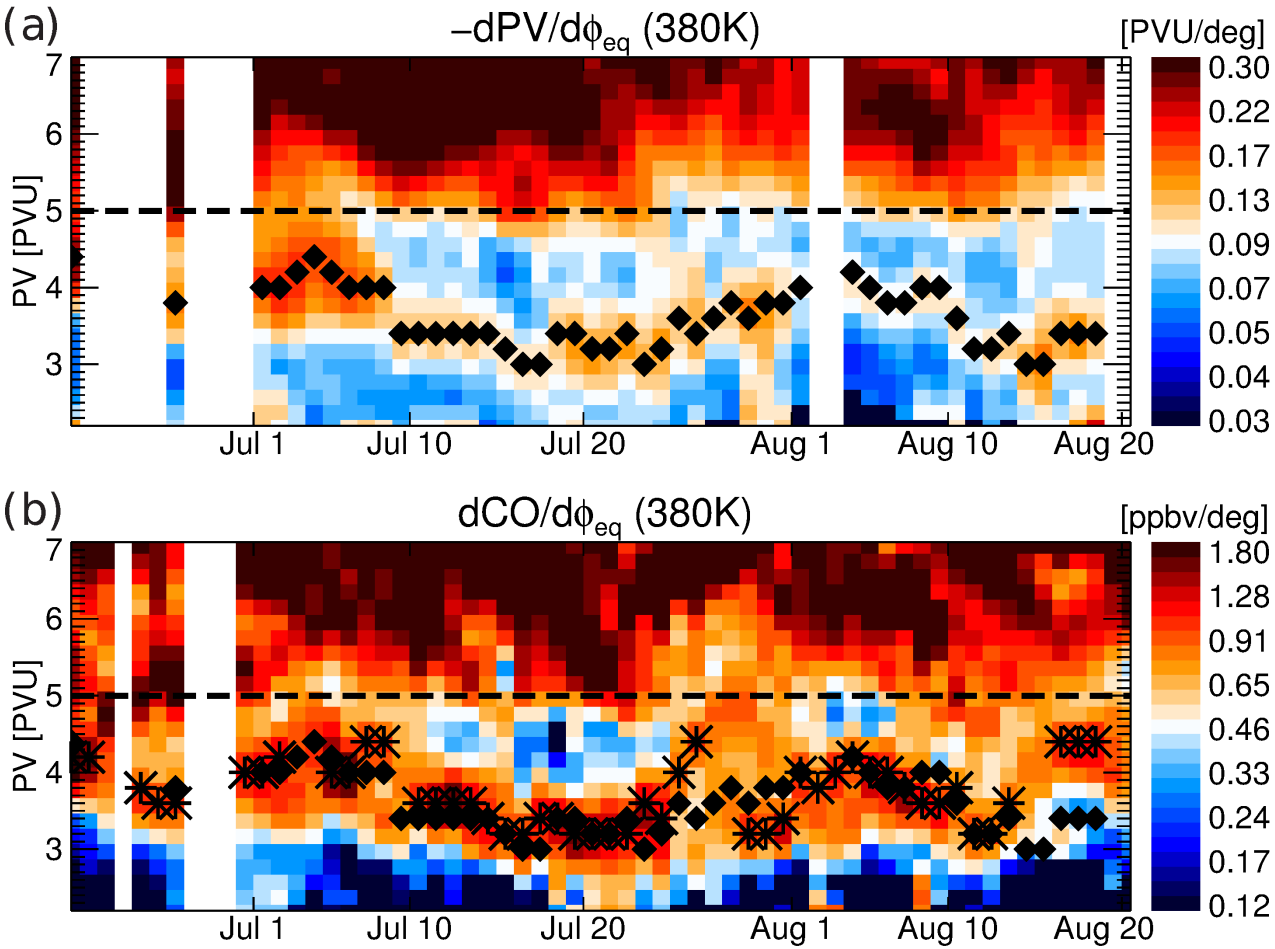


Mean age



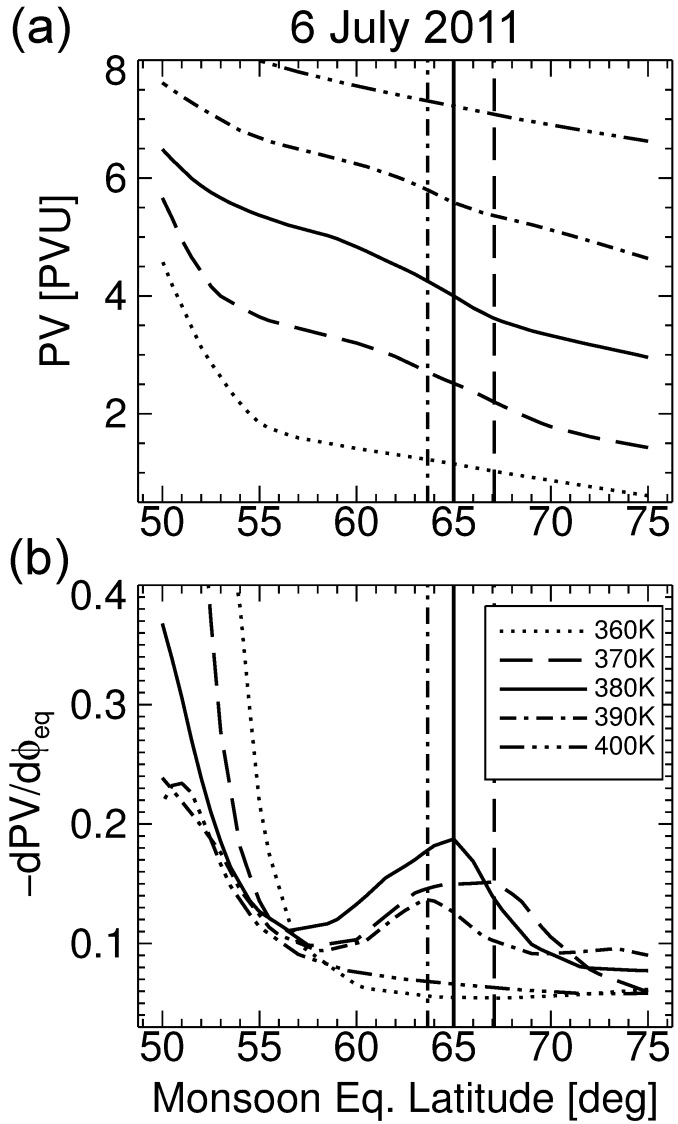
- Map tracers versus monsoon equivalent latitude
- PV-barrier agrees well with enhanced tracer gradients!

Time-evolution of transport barrier



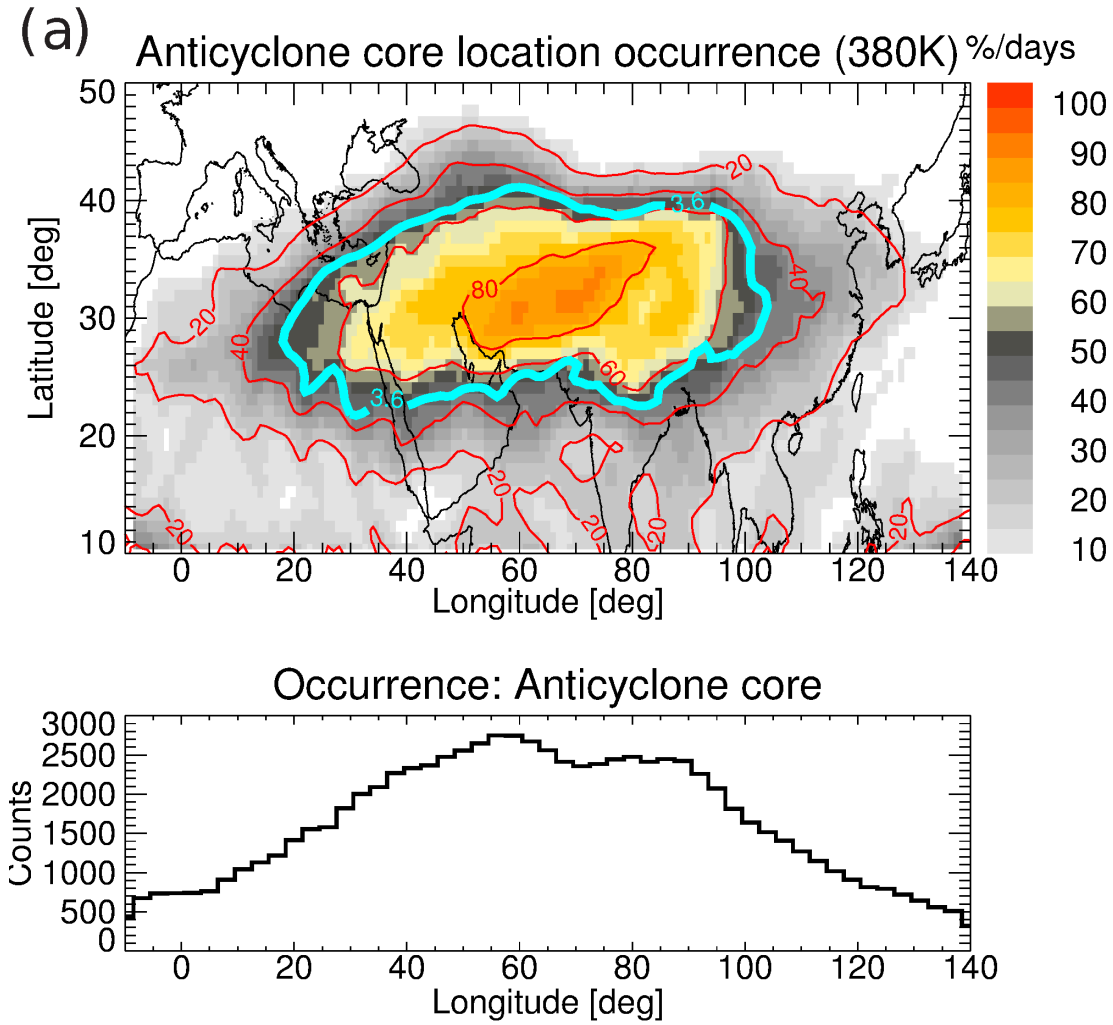
- Good agreement: PV-barrier $\leftrightarrow$ max. CO-gradient
- average PV-value of barrier (380K / summer 2011): 3.6 PVU

PV-barrier at different levels



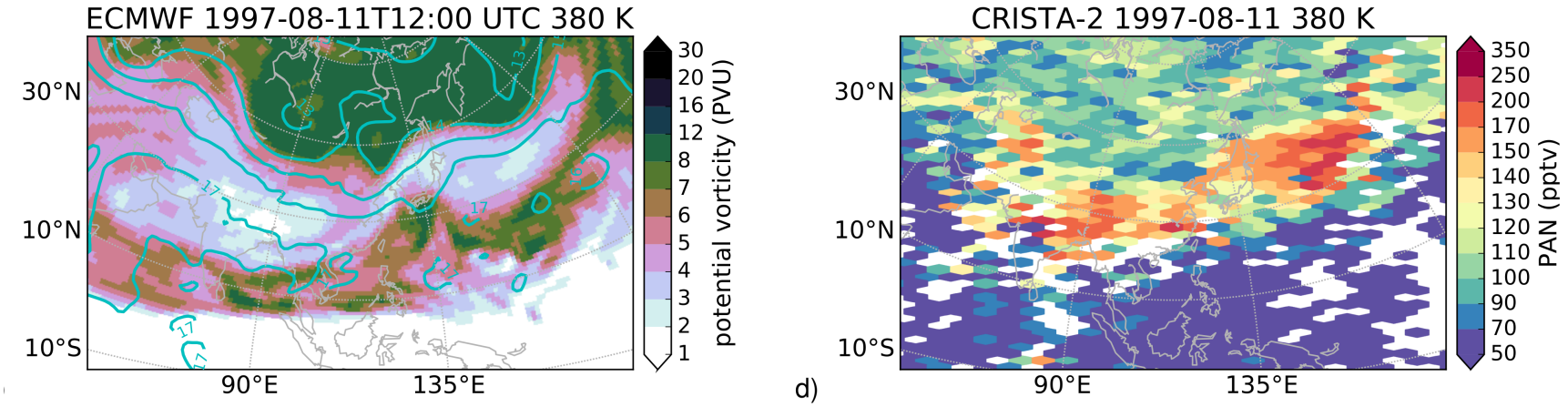
- below ∼360 K: jet too strong
- above ∼400 K: in stratosphere
- PV-barrier only between 370–390K

Anticyclone location probability



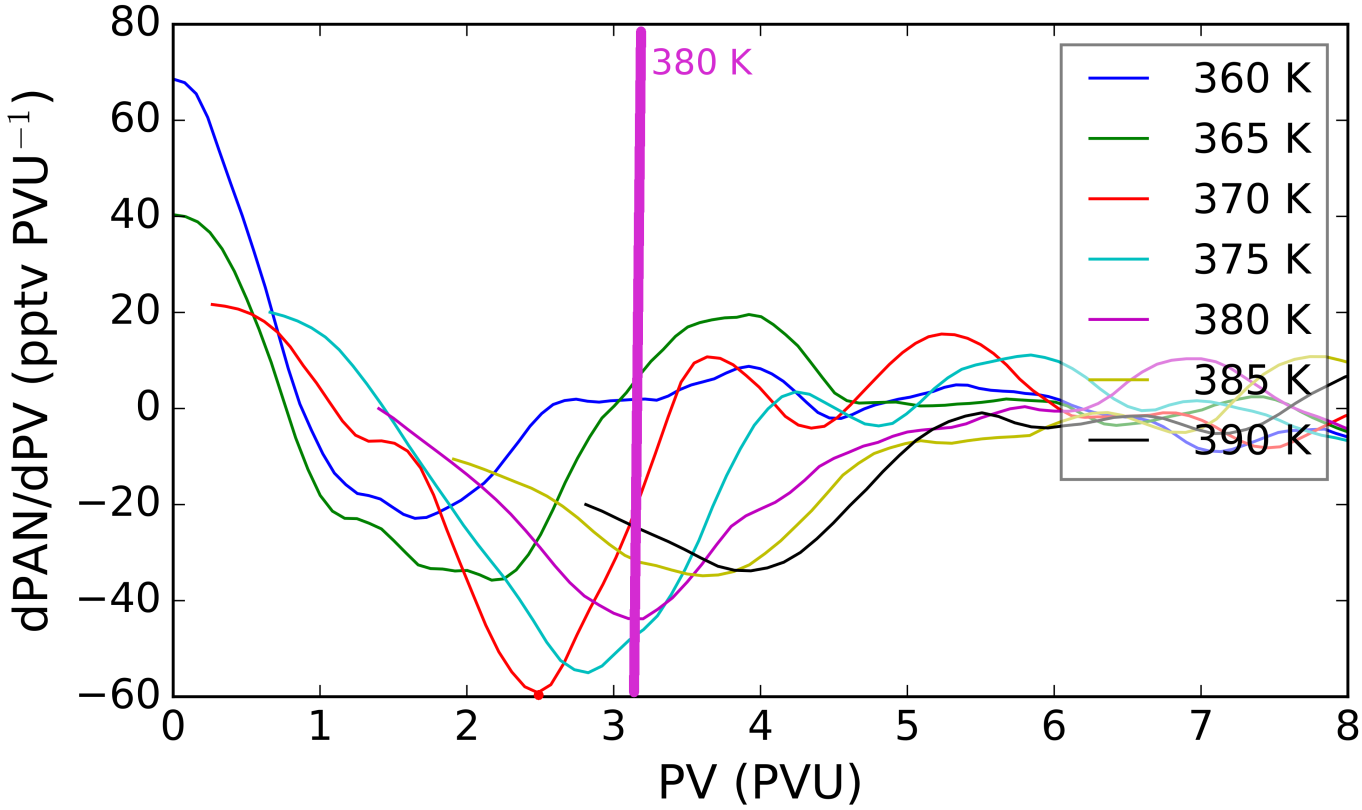
- frequency for being located inside anticyclone core
- bimodal pdf - only if projected onto longitude [Zhang et al.,2002]

CRISTA PAN-observations (380K, August 1997)



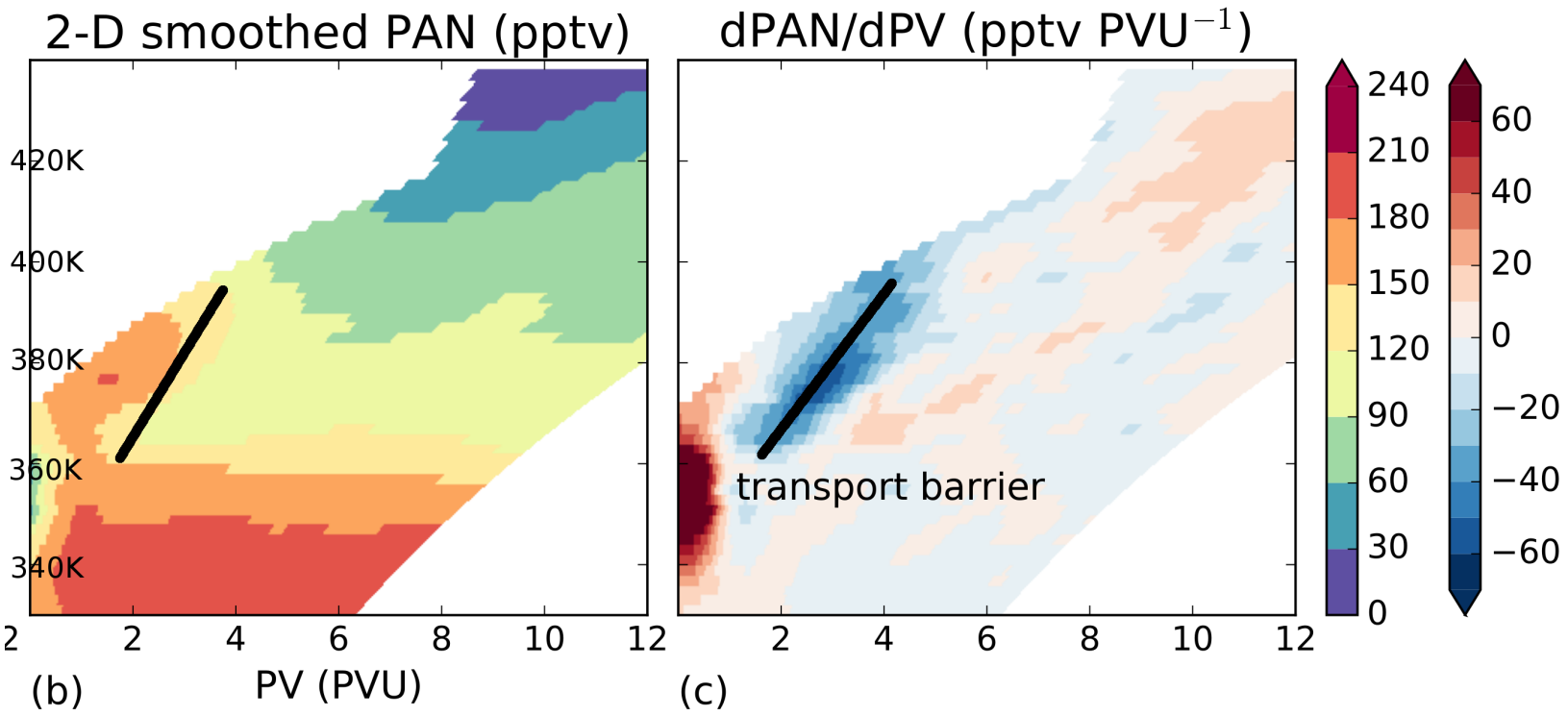
- PAN-measurements from CRISTA show confinement in anticyclone (Ungermann et al., 2016, ACPD)
- PAN contours closely follow PV

CRISTA PAN-observations & PV-gradient barrier



- enhanced Pan-gradients at edge of anticyclone

CRISTA PAN-observations & PV-gradient barrier



- Transport barrier visible between 360-400 K

Age spectrum in the Asian monsoon

CLaMS age spectrum from **B**oundary **I**mpulse t-**E**volving **R**esponse (**BIER**)

(Ploeger & Birner, 2016, ACPD)

Age spectrum in the Asian monsoon

CLaMS age spectrum from **B**oundary **I**mpulse t-**E**volving **R**esponse (**BIER**)

(Ploeger & Birner, 2016, ACPD)

$\Rightarrow$ *German version of BIR-method by (Li et al., 2012)*

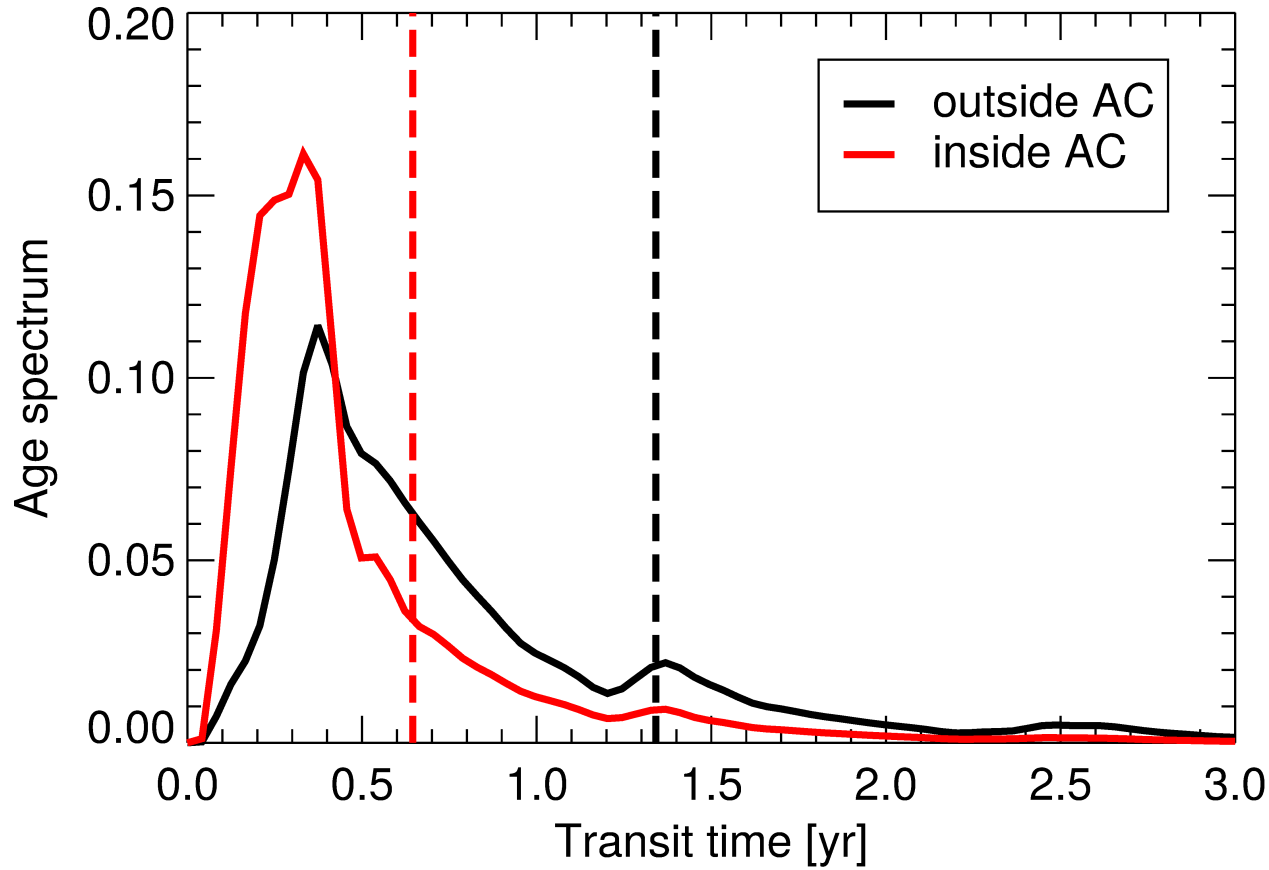
Age spectrum in the Asian monsoon

CLaMS age spectrum from **B**oundary **I**mpulse t-**E**volving **R**esponse (**BIER**)

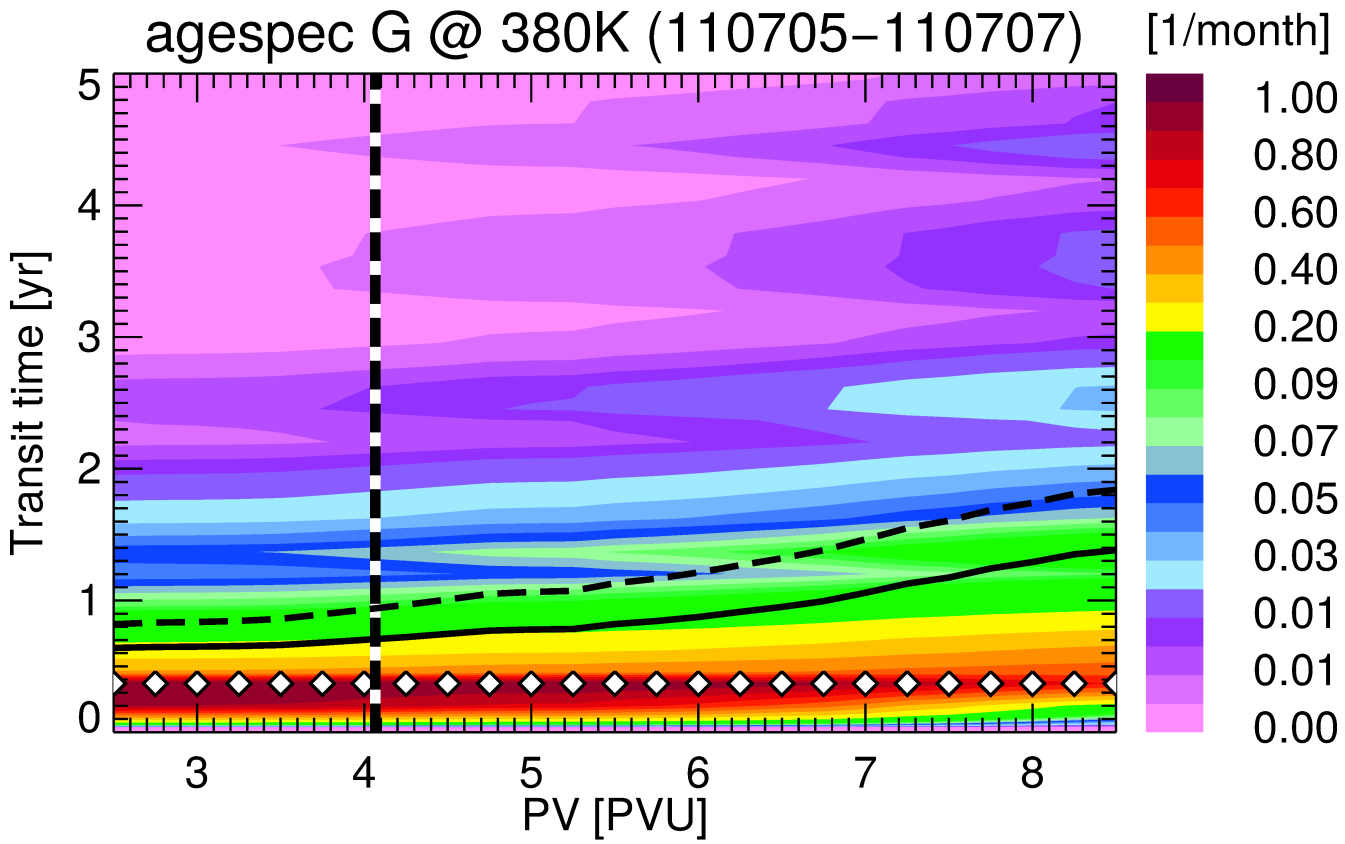
(Ploeger & Birner, 2016, ACPD)

⇒ *German version of BIR-method by (Li et al., 2012)*

- *higher fraction of young air inside anticyclone than outside*

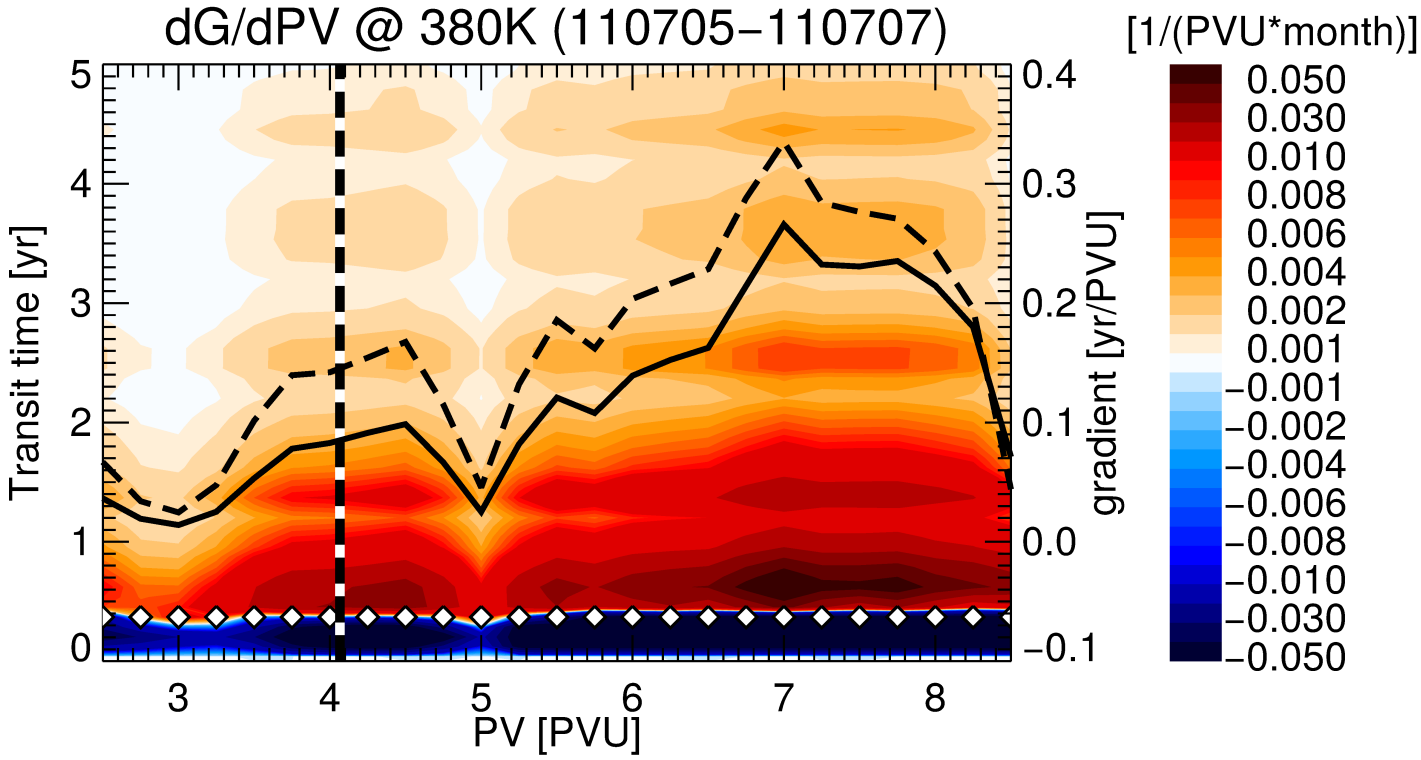


Monsoon age spectra vs. PV (380 K)



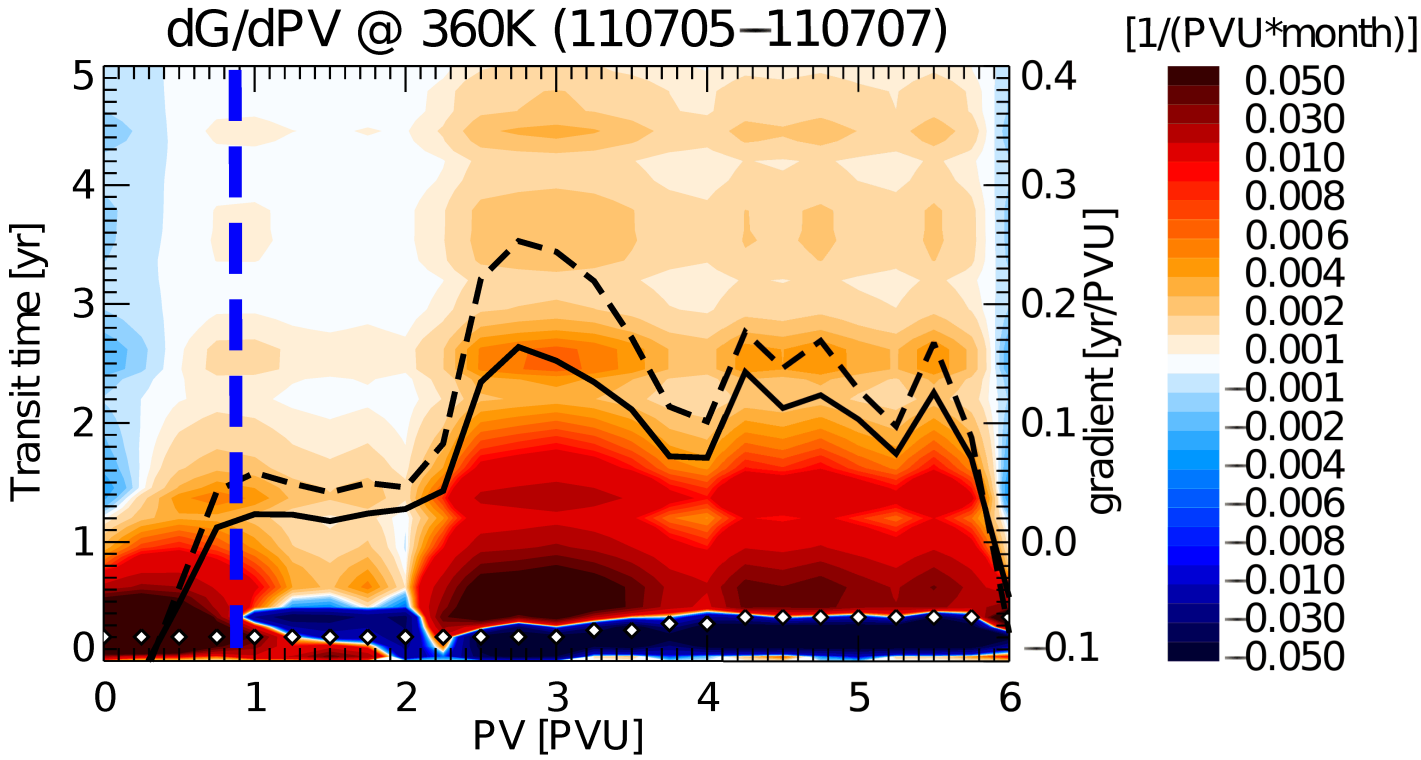
- PV-barrier separates between young & old air
- monomodal shape inside – multimodal shape outside

Monsoon age spectra vs. PV (380 K)



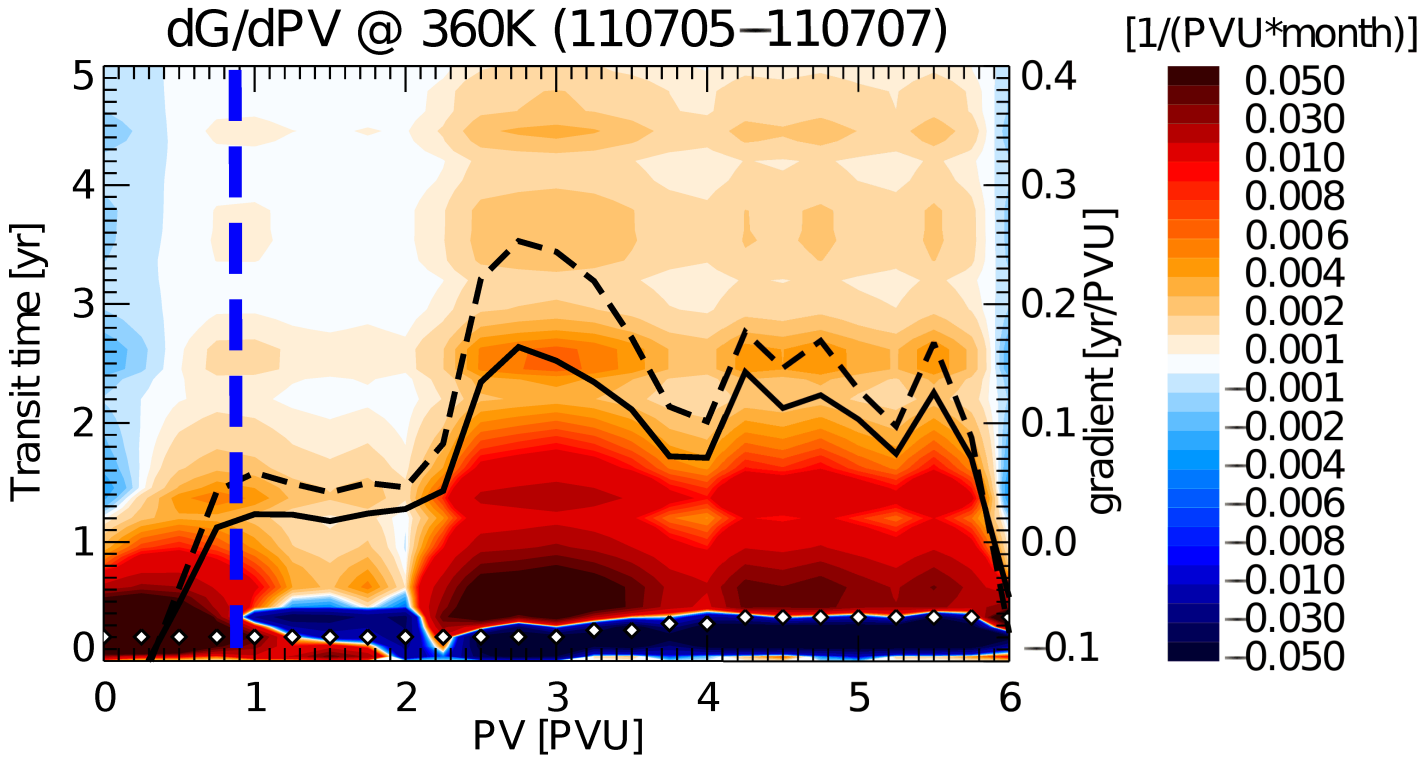
- max. gradient in young/old air fraction at PV-transport barrier
- old air shows similar info about confinement than young air

Monsoon age spectra vs. PV (360 K)



- indication for transport barrier even at 360 K

Monsoon age spectra vs. PV (360 K)



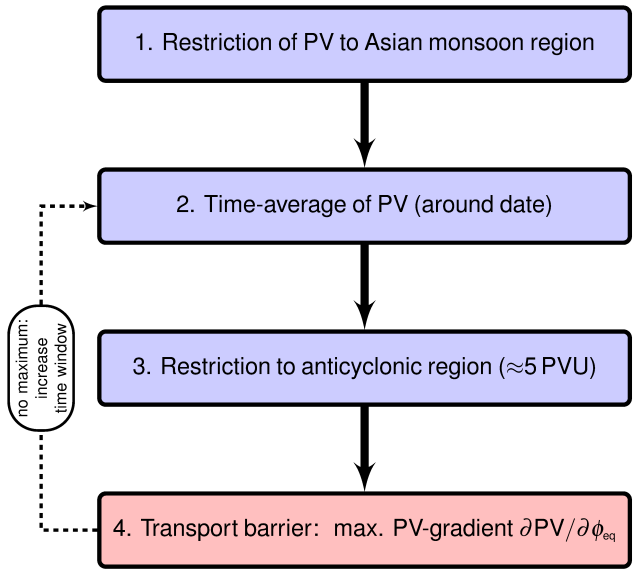
- indication for transport barrier even at 360 K

BIER to understand monsoon transport!

age spectrum ⇒ transport timescales
& young/old air fraction

Conclusions

- Transport barrier from PV-gradient for Asian monsoon anticyclone:



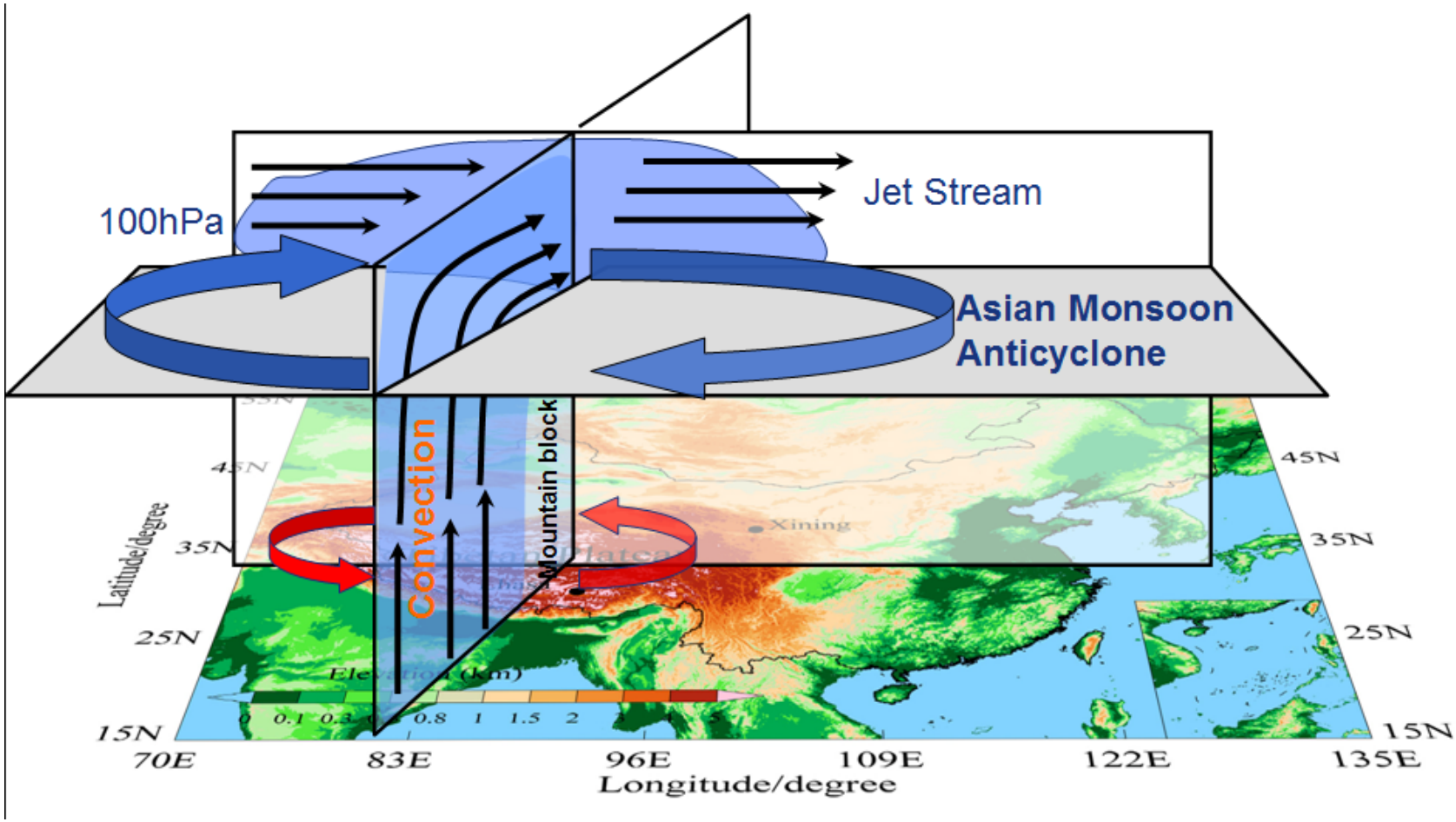
- PV-barrier separates air of different chemical characteristics
- Outlook: BIER for understanding monsoon
  - why PV-barrier not deducable for all dates with tracer-anomalies...?
  - difference in transport characteristics in-/outside anticyclone?
  - ...
- See what STRATOCLIM in–situ data will show ...

APPENDIX

▸ mons ▸ pdf ▸ ts-CRISTA ▸ circ ▸ BIER ▸ lin

Asian summer monsoon (Jul–Aug)

app



- troposphere: cyclone, convergence / stratosphere: anticyclone, divergence
- strong upward transport in monsoon (convection & slow steady uplift)

Transport barrier from CO mixing ratio PDF

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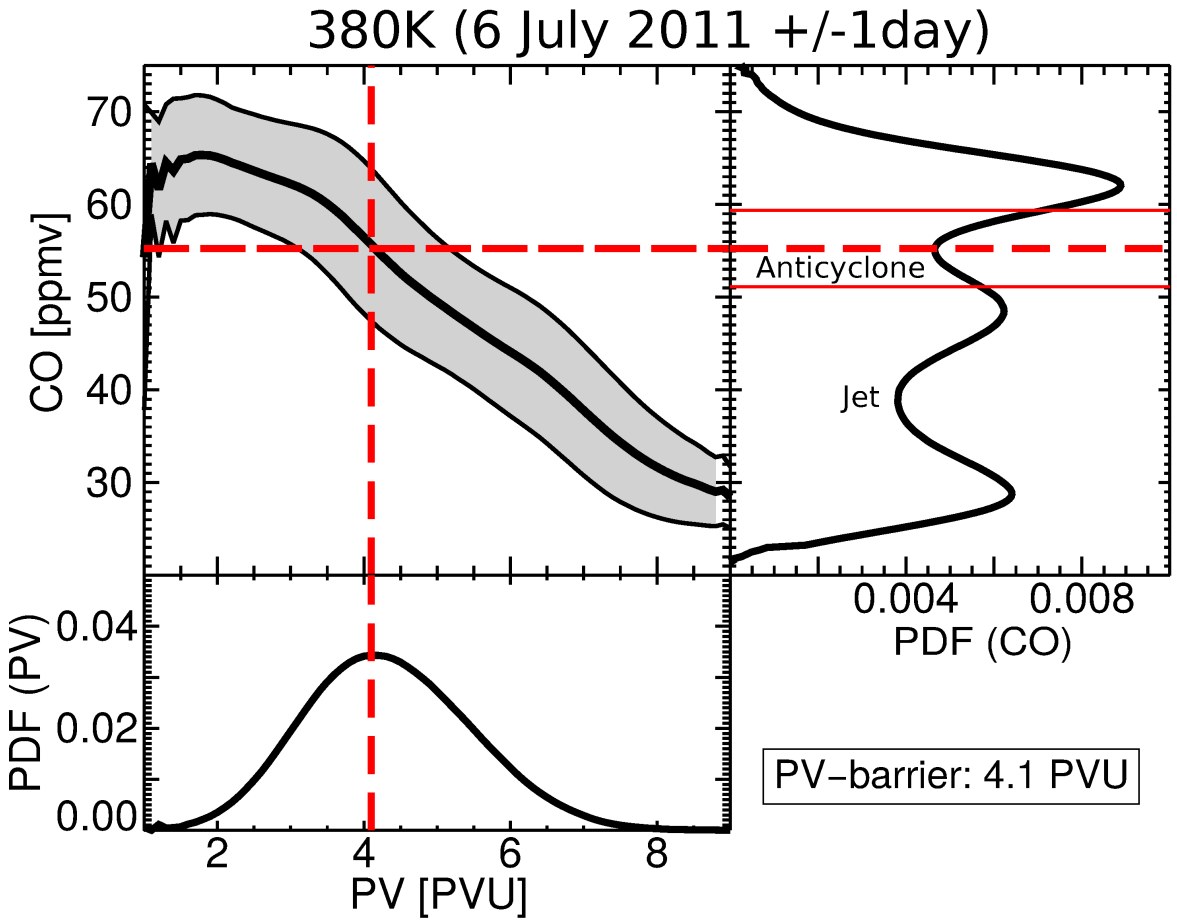

- Good agreement with PV-gradient barrier of 4 PVU
  (method by [Sparling et al.,2000])

Time-evolution of transport barrier (Aug/1997)

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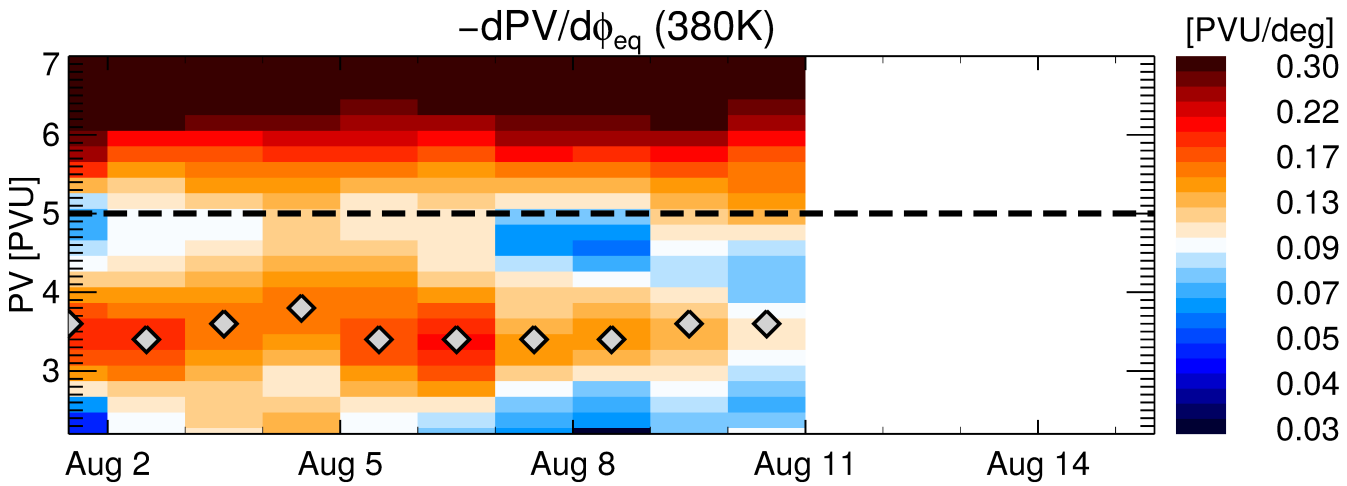

- well-defined PV-barrier at 380 K until mid-August

Method: Separate from subtropical jet

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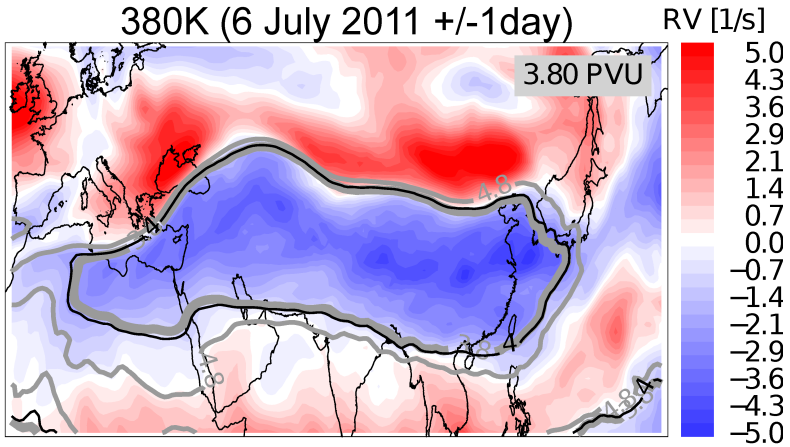

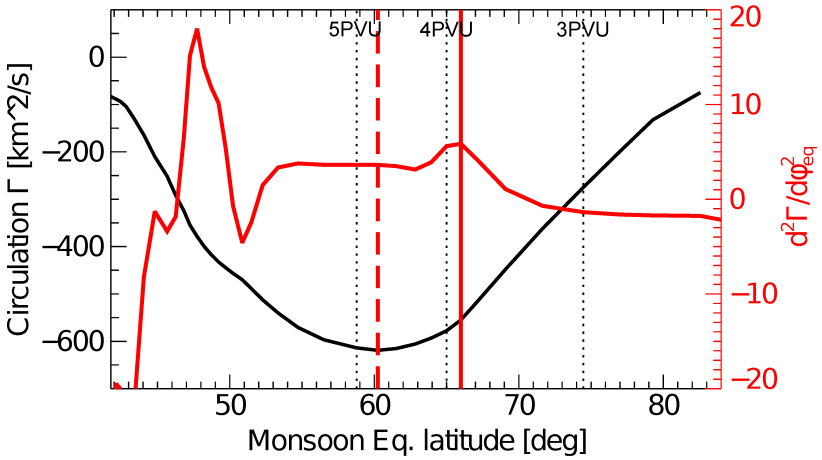

- Assumption:
  neg. vorticity in anticyclone
- circulation

$$\Gamma = \oint_S \mathrm{d}\boldsymbol{s} \cdot \mathrm{v} = \int_A \mathrm{d}a\, \zeta$$

minimum $\leftrightarrow$anticycl. boundary

$\Rightarrow$ approx. by 5 PVU at 380 K

Method: multi-pulse technique [e.g., Li et al., 2012]

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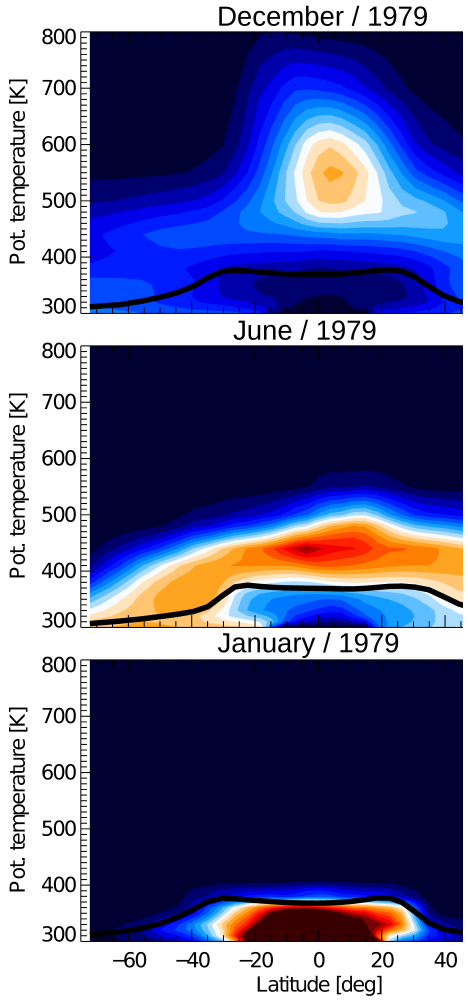
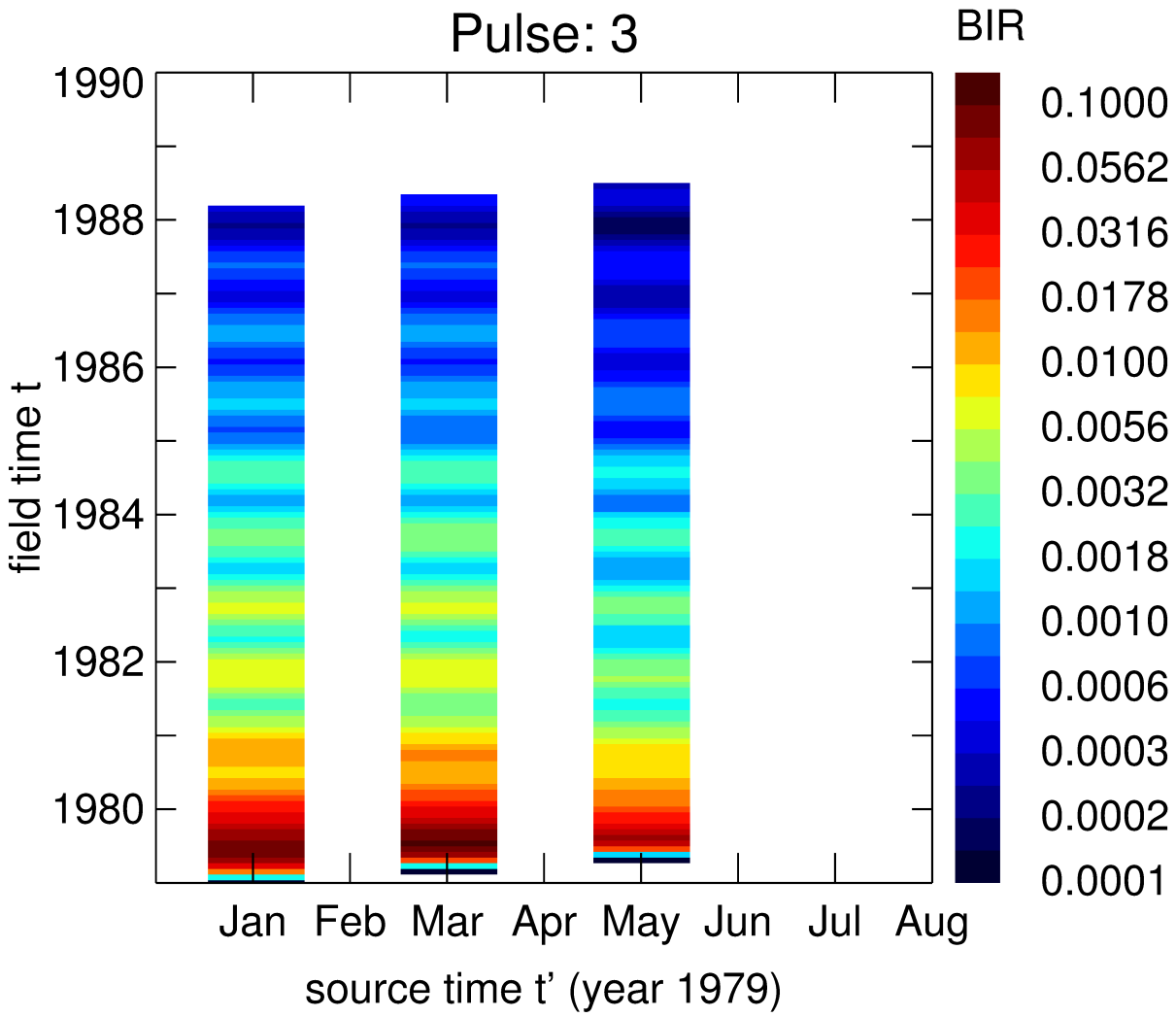
- for tracer χ^1 with pulse at surface at t_1': $G(r, \boldsymbol{t}, t_3') = \chi^3(r, \boldsymbol{t})$
- release pulse & measure evolution $\Rightarrow$ propagator map $G(r, t, t')$





CLaMS set-up:
development of Boundary Impulse Response (BIR) method [Li et al., 2012]

- climatological run 1979–2015 (ERA-Interim)
- $N = 60$ pulse tracers
- Ω is tropical boundary layer (15°S–15°N)
- 30-day pulses every second month $\Rightarrow$ age spectrum for 10 years
- re-initialize first pulse after 10 years (transient simulation)

  $\Rightarrow$ "**B**oundary **I**mpulse (time-)**E**volving **R**esponse (**BIER**)" method

Seasonality of age spectrum

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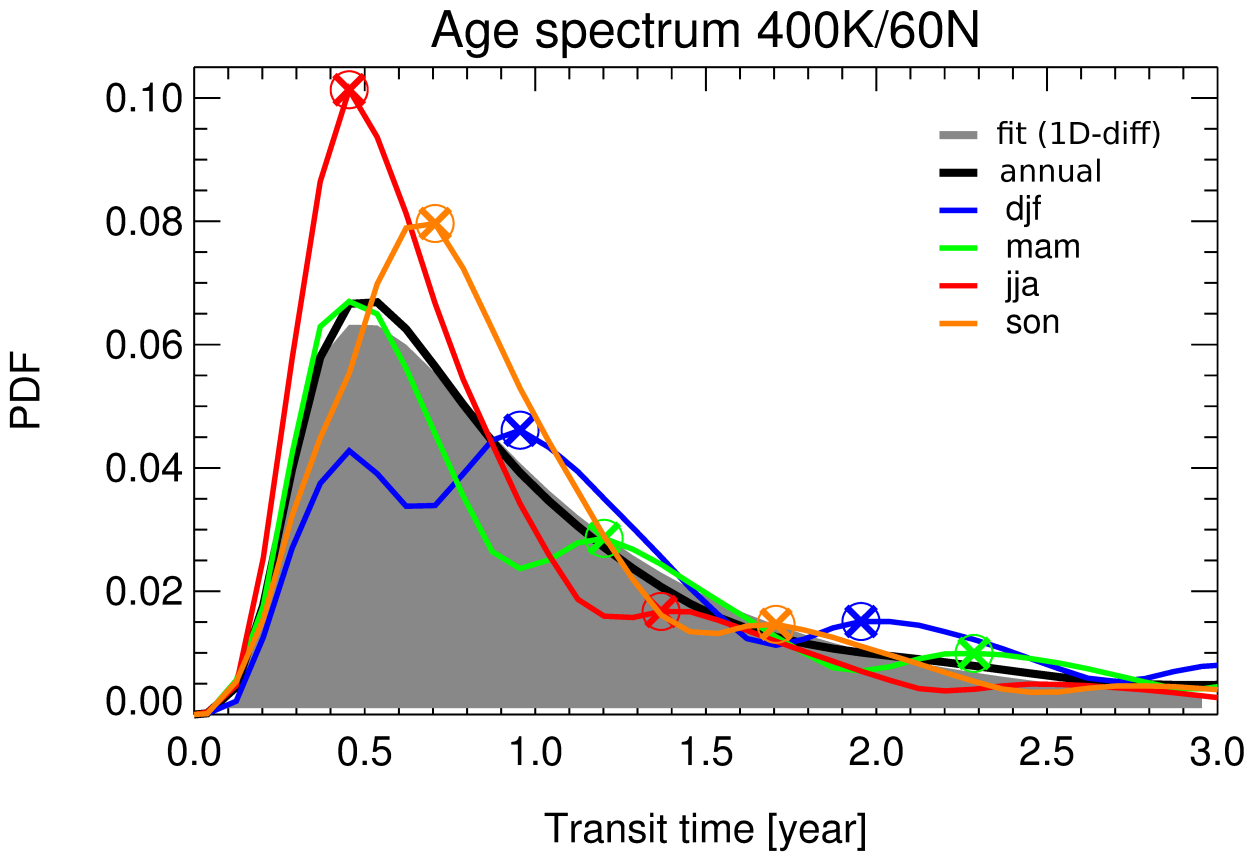

- annual mean age spectrum fits well stationary 1D-diffusion Greens function [Hall & Plumb, 1994]
- but strong seasonality & multiple peaks (annually repeating)

Seasonality: Cause for multiple peaks

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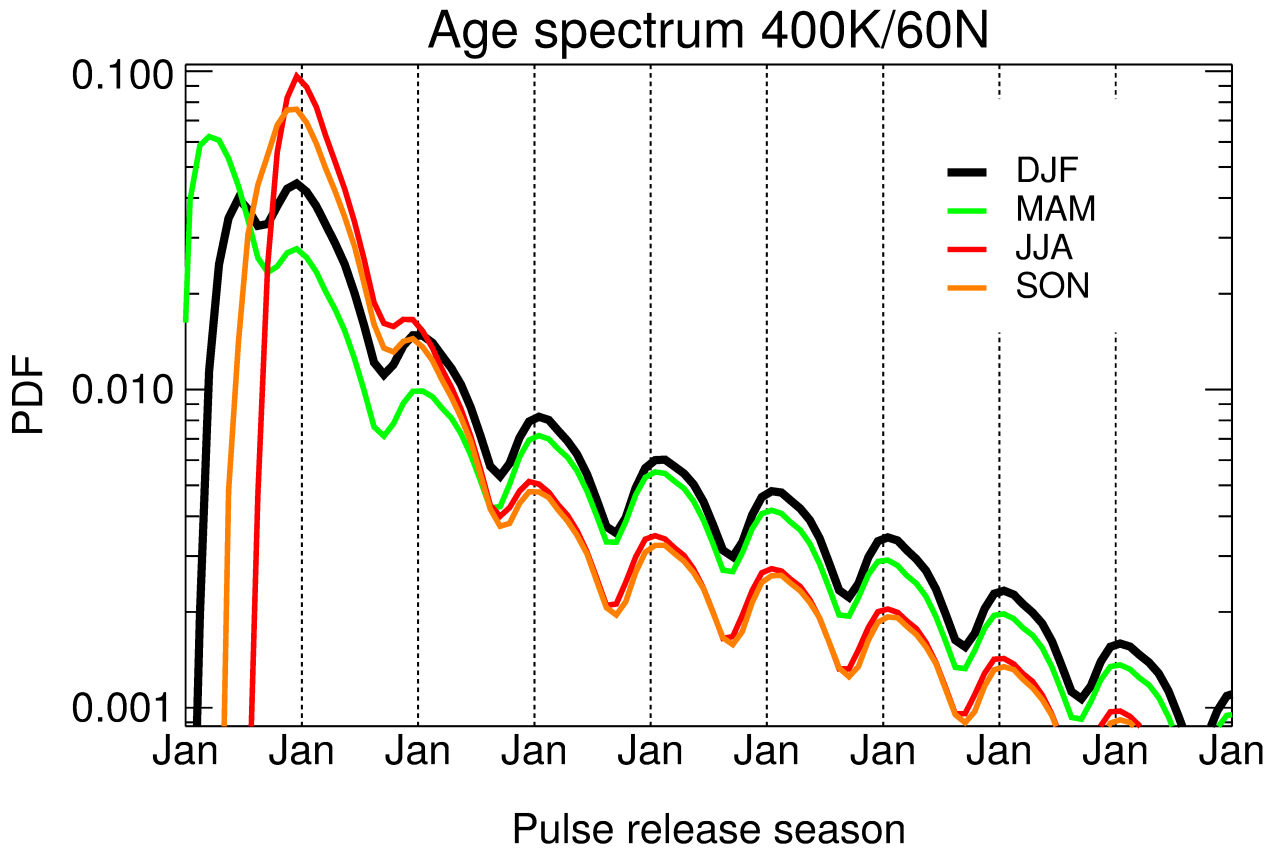

- shift: transit-time x-axis $\rightarrow$ season of pulse release
- peak air $\Rightarrow$ left Earth's surface in NH winter

Seasonality: Cause for multiple peaks

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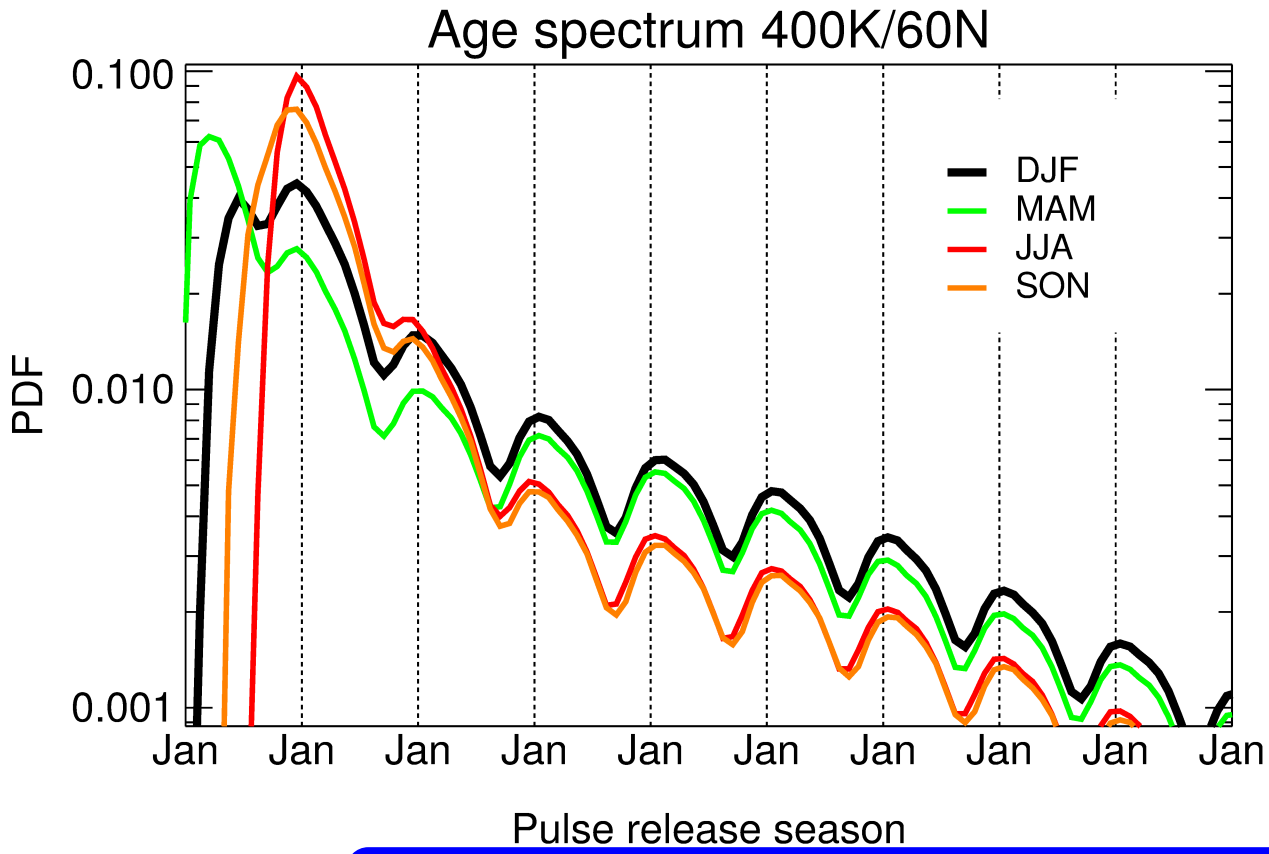

- shift: transit-time x-a
- peak air ⇒ left Earth

peaks ⇔ max. probability of winter surface air: