Trends of stratospheric mean age of air, and the effects of residual circulation and mixing in ERA-Interim and JRA-55

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J. Geophys. Res. (doi:10.1002/2014JD022468),
Geophys. Res. Lett. (doi:10.1002/2014GL062927)

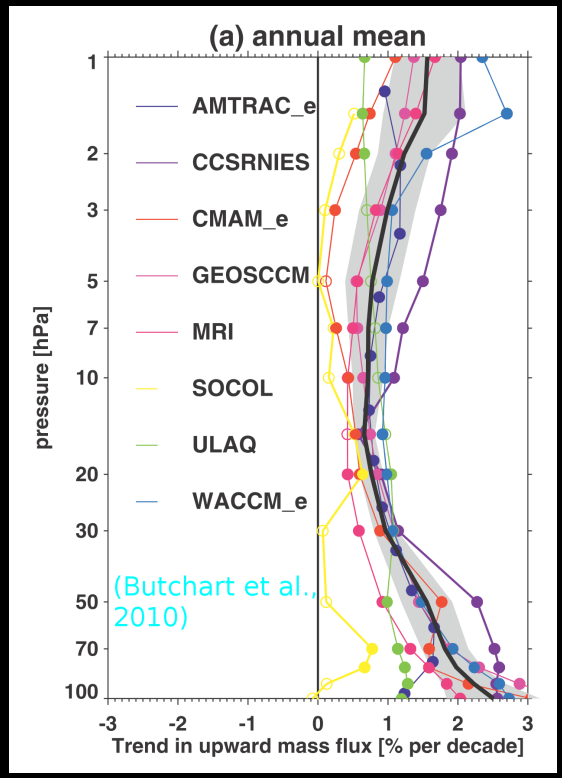
and more...

S–RIP workshop 2015, Paris

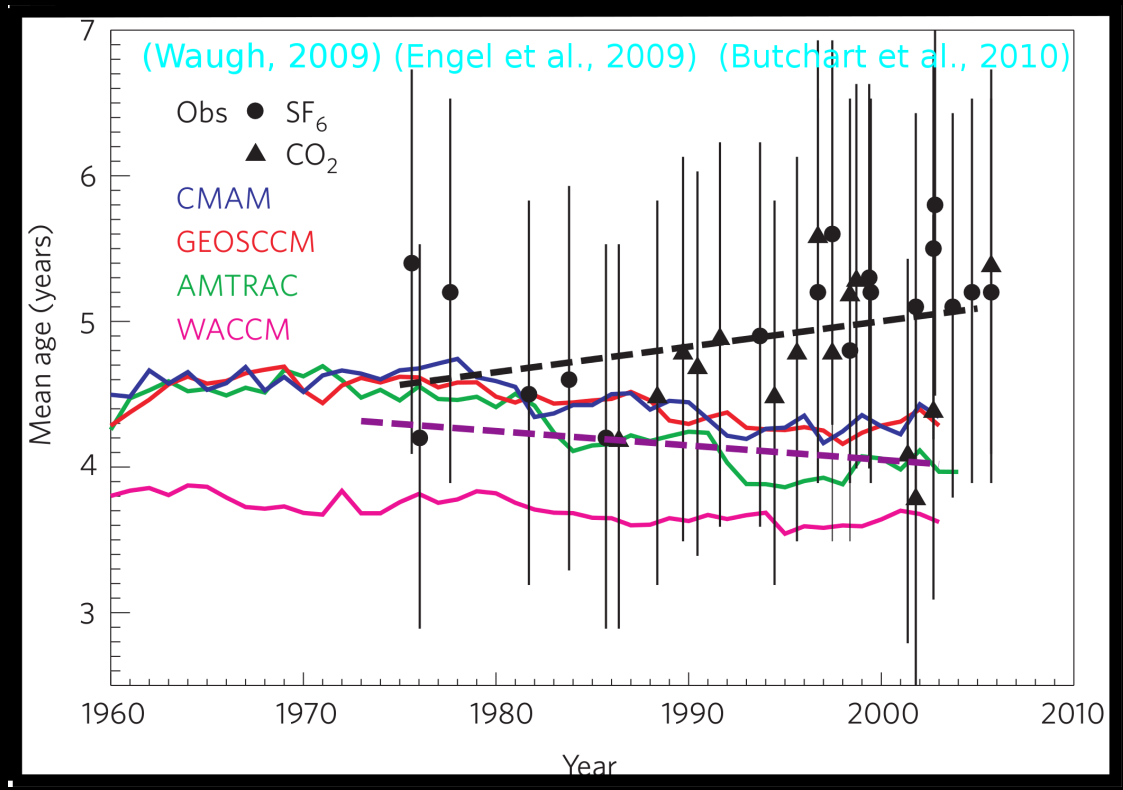
JÜLICH FORSCHUNGSZENTRUM

Motivation

★ **Models:** BDC upwelling increase



★ **Mean age:** average transit time
⇒ common measure for circulation



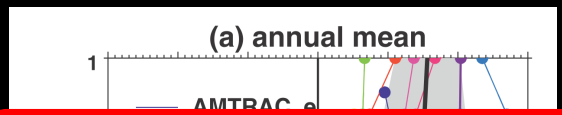
BDC-Puzzle: acceleration or deceleration?

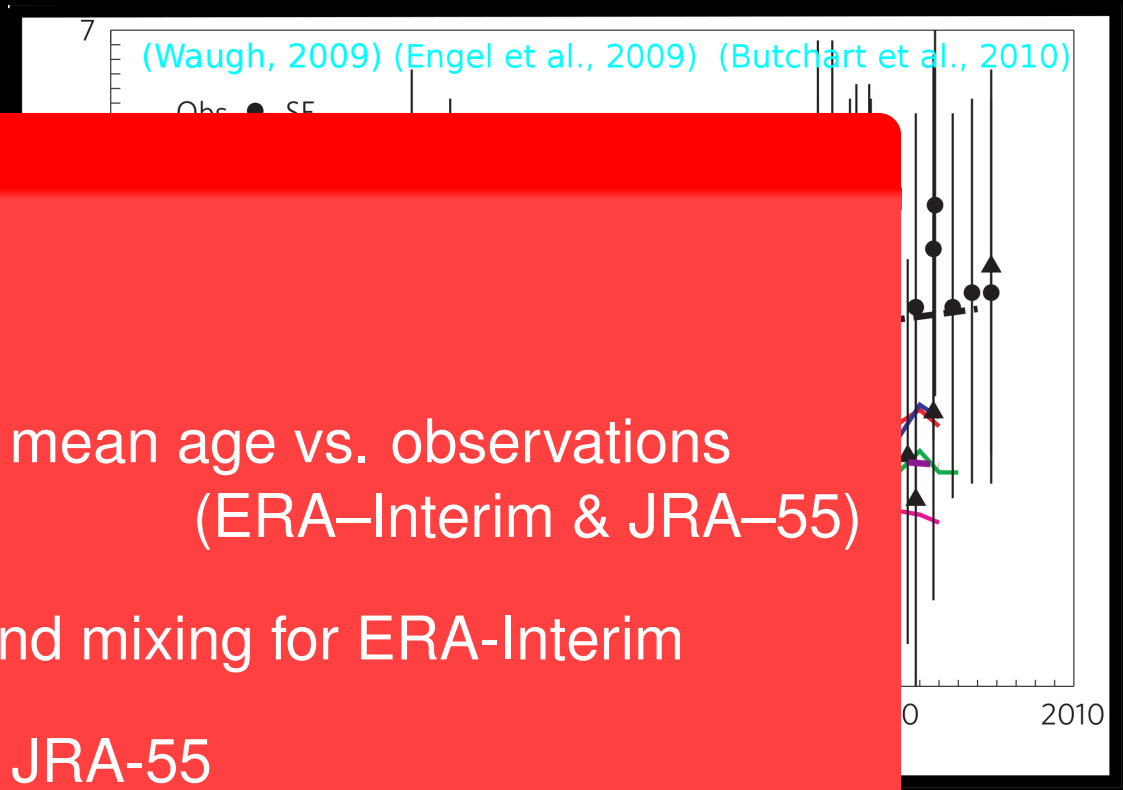
⇒ analyze processes involved
(residual circulation & mixing)!

Motivation

★ **Models:** BDC upwelling increase

★ **Mean age:** average transit time
⇒ common measure for circulation



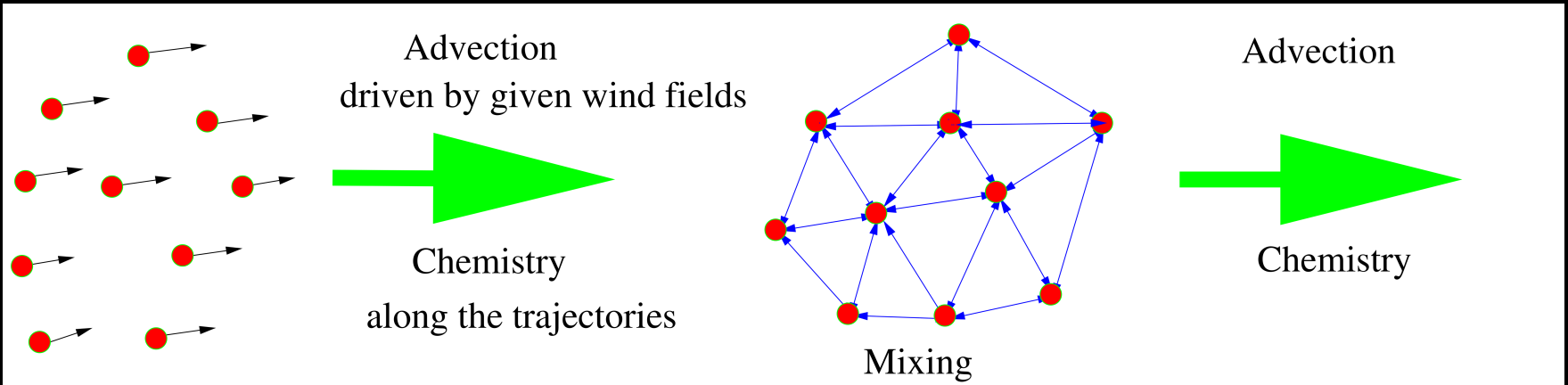


Outline:

1. Motivation
2. Validation: CLaMS mean age vs. observations (ERA–Interim & JRA–55)
3. Mean age trends and mixing for ERA-Interim
4. ...and the same for JRA-55
5. Conclusions

1. Our tool: the Lagrangian CTM CLaMS

★ **C**hemical **La**grangian **M**odel of the **S**tratosphere: trajectory based CTM

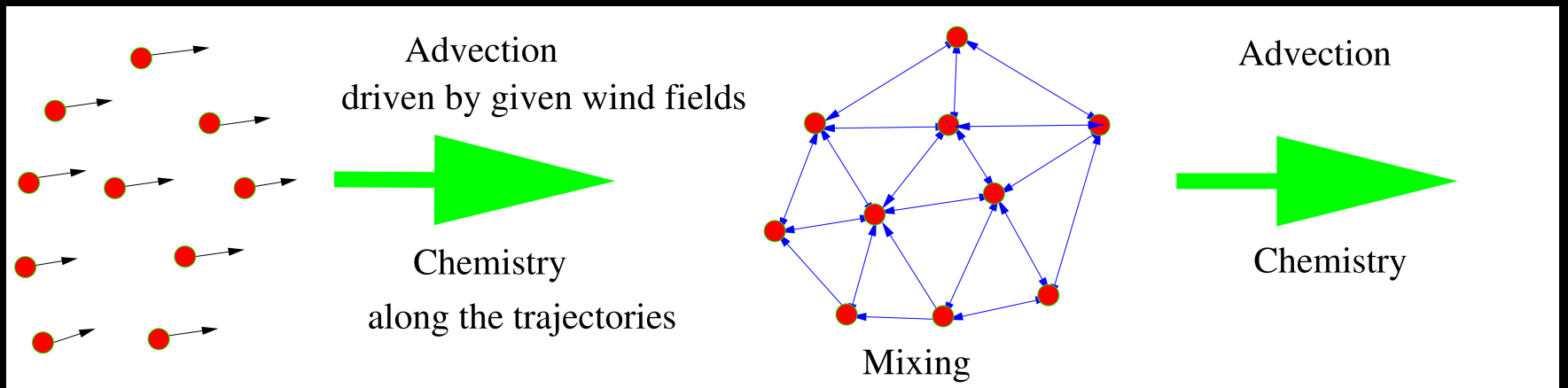


Tracer transport = Advection (Trajectories) (reversible) + Mixing (Adaptive grid) (irreversible)

(courtesy of Paul Konopka)

1. Our tool: the Lagrangian CTM CLaMS

★ **C**hemical **La**grangian **M**odel of the **S**tratosphere: trajectory based CTM



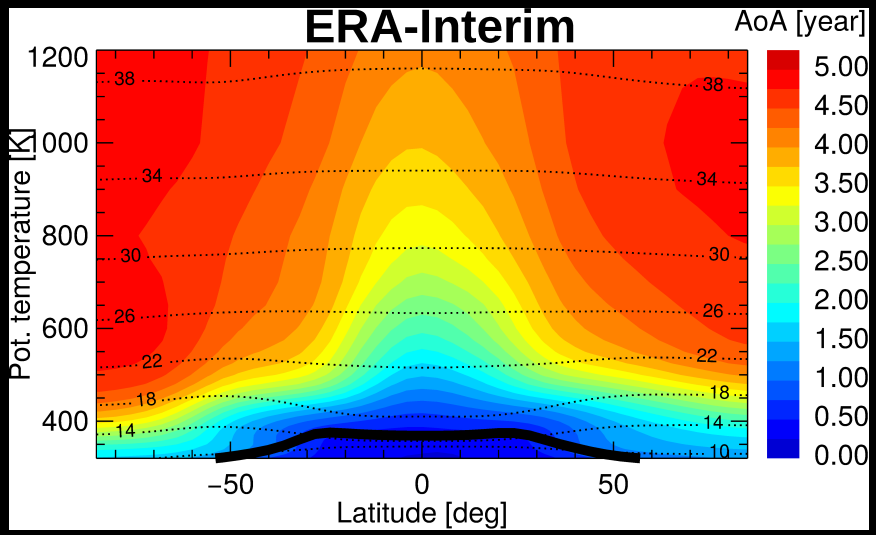
Trace
trans
d)

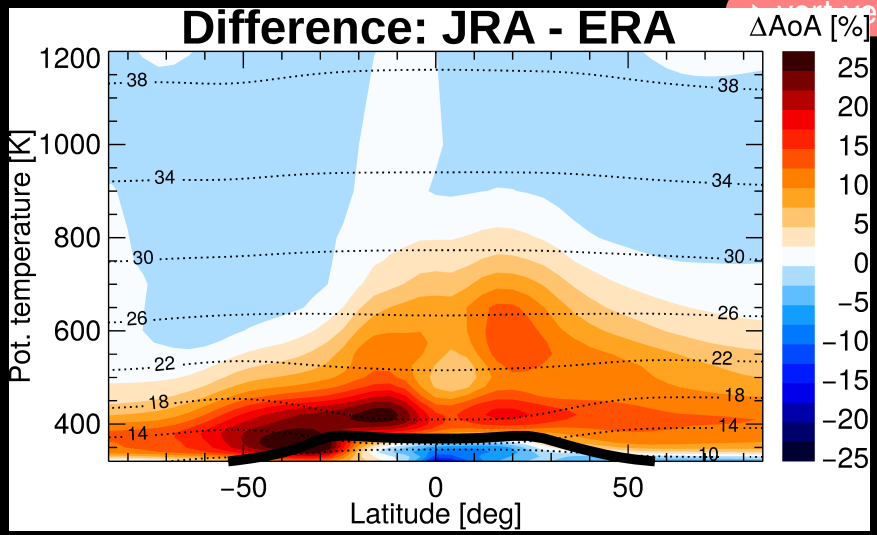
Two long-term CLaMS Simulations:

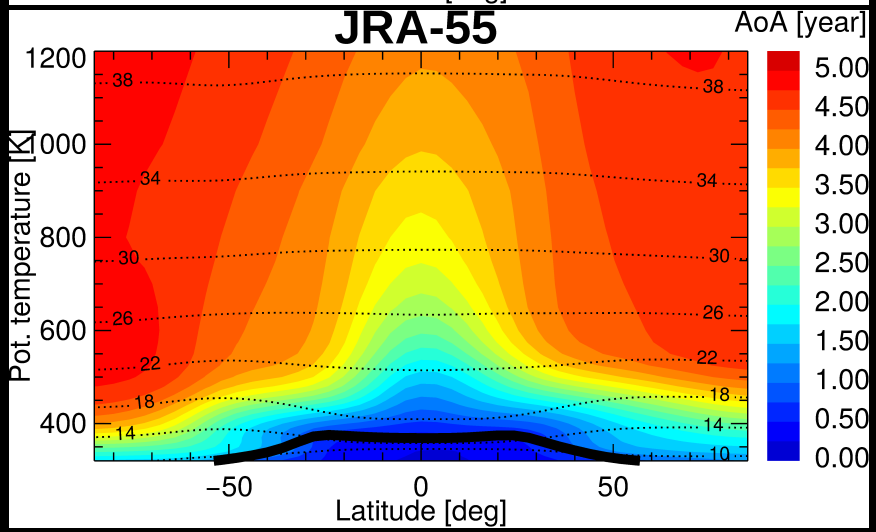
- winds & temp from ERA-Interim & JRA-55
- period: 1979–2013
- isentropic vertical coordinate
  → vert. velocity from diabatic heating rate
- 'clock-tracer' age

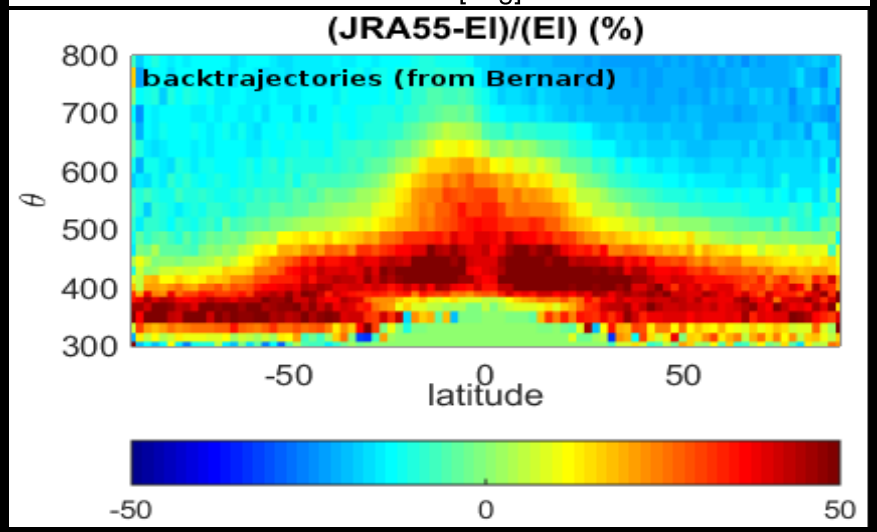
Paul Konopka)

2. Validation of CLaMS model vs. observations



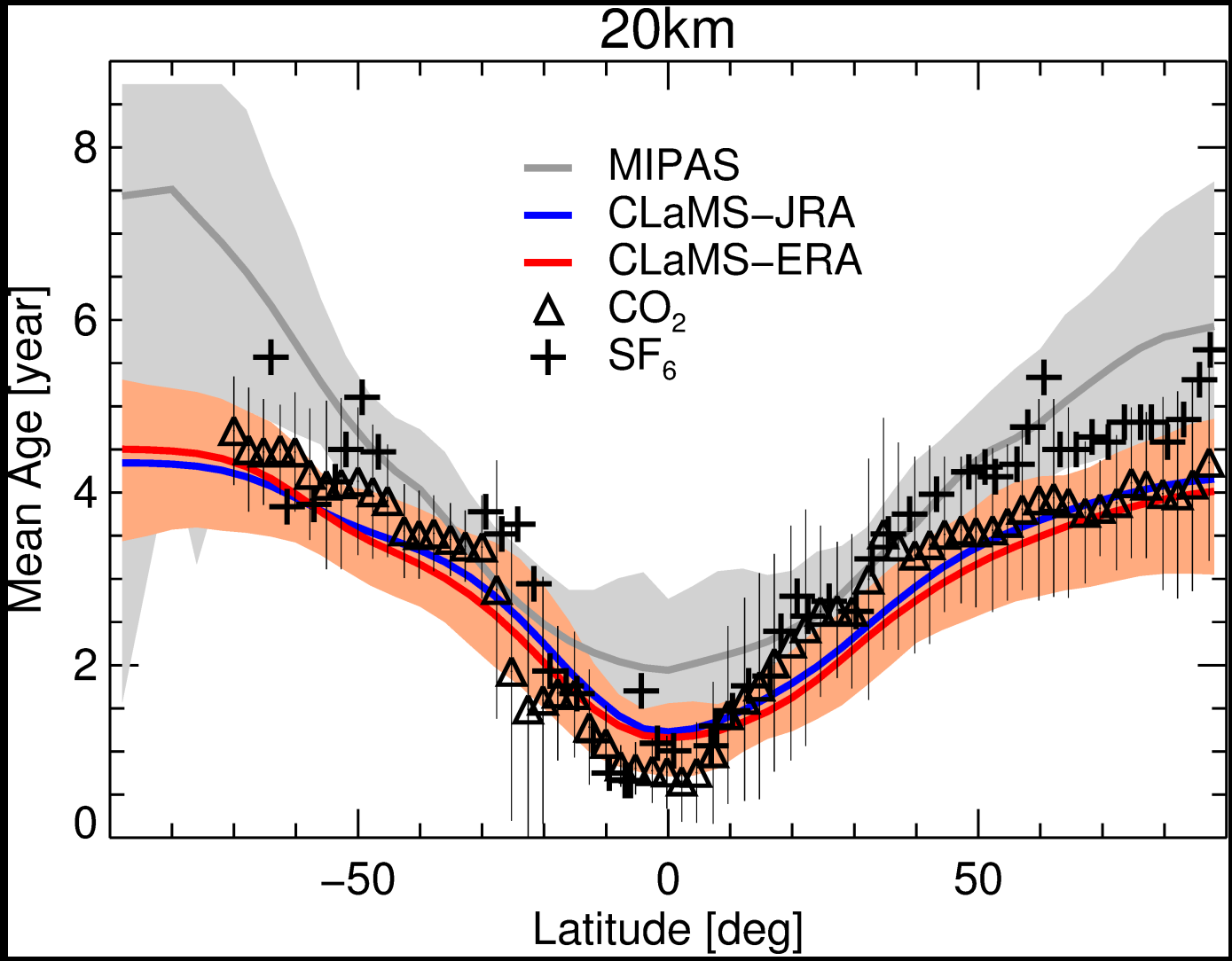






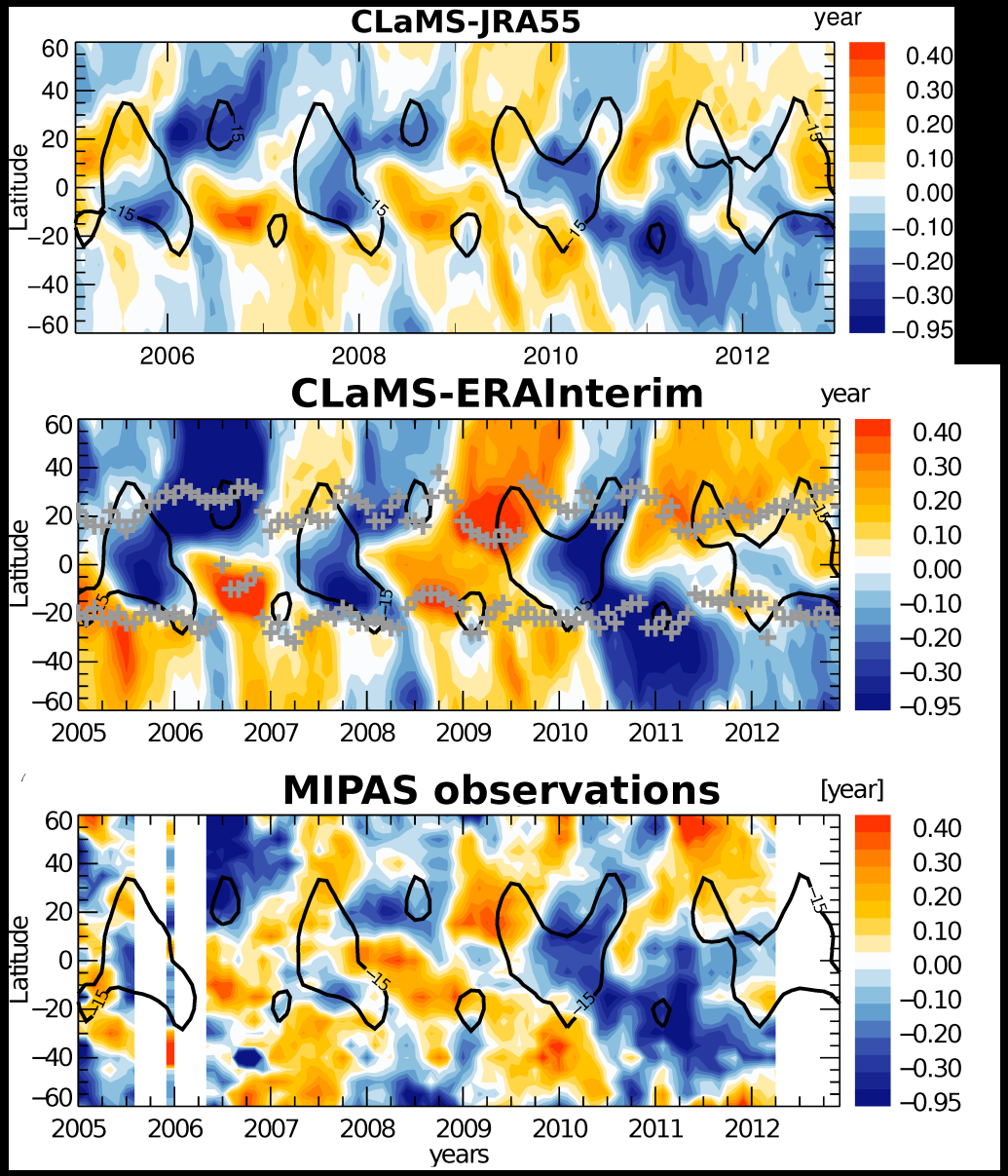
★ climat. age similar for ERA & JRA! (lower strat.: ERA younger)

Comparison: CLaMS model vs. observations (@ 20km)



★ reliable agreement: CLaMS ↔ observations ... **for ERA & JRA!**

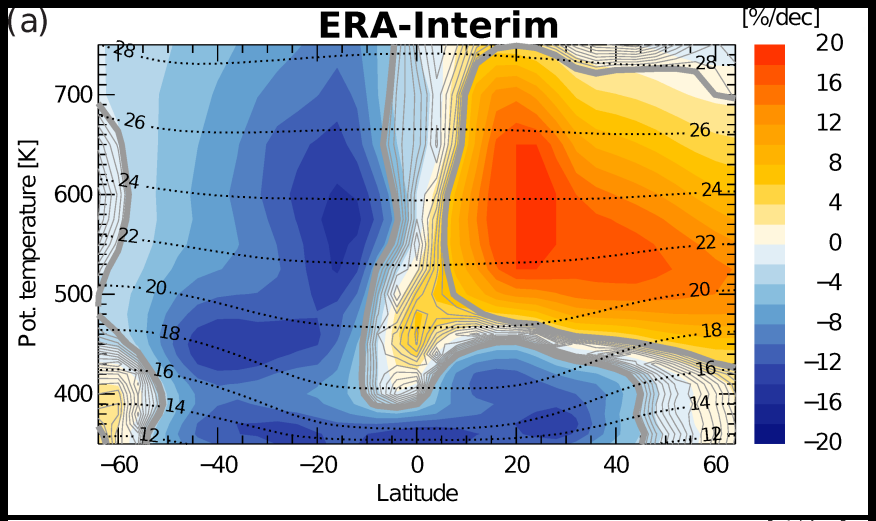
Mean age variability (25 km): CLaMS vs. MIPAS observations

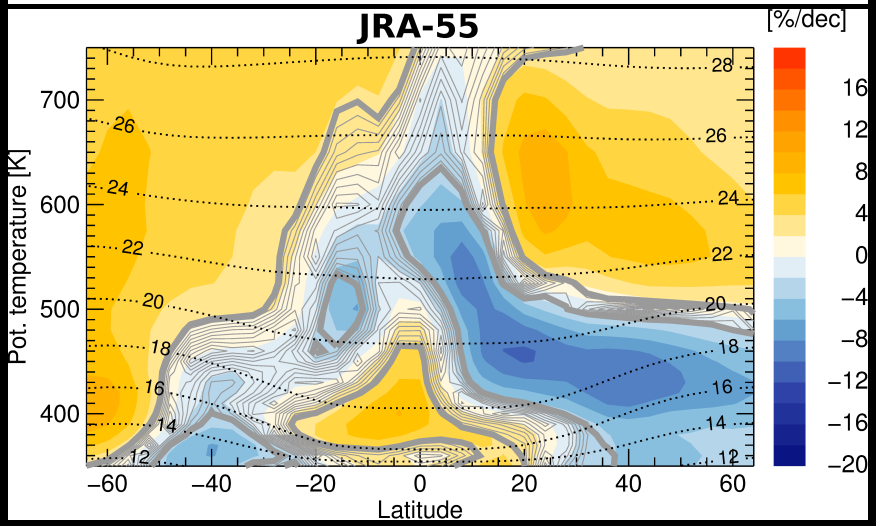


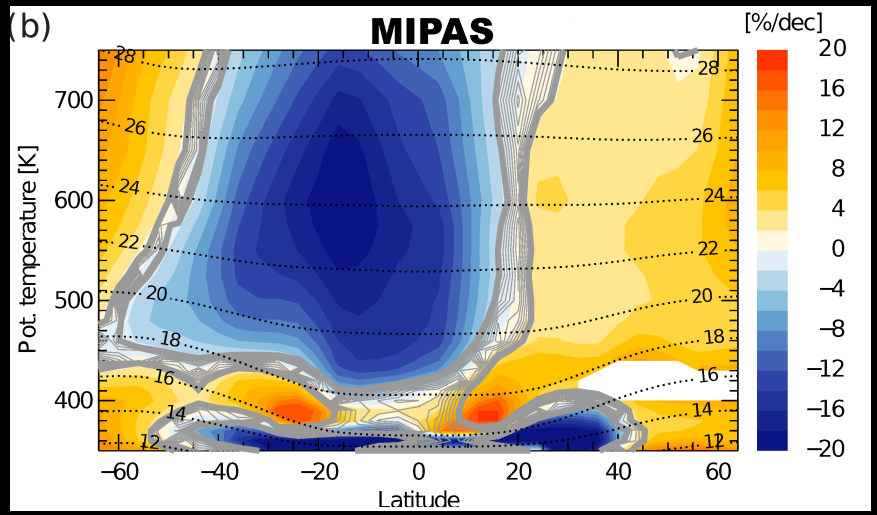
- ★ good agreement: CLaMS–MIPAS **...for both ERA & JRA!**
- ★ strong QBO-variability!

Decadal trend 2002–12: CLaMS vs. MIPAS observations

▸ MMM-MIP







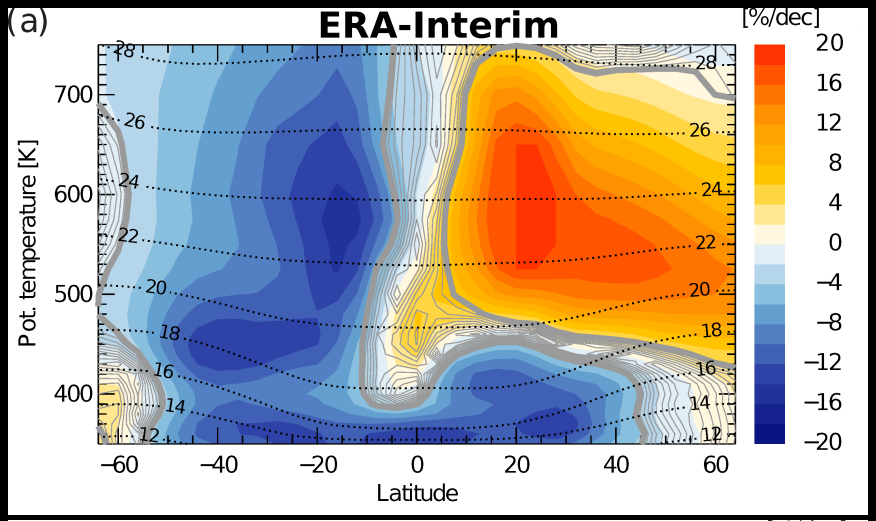
★ Agreement CLaMS–MIPAS:

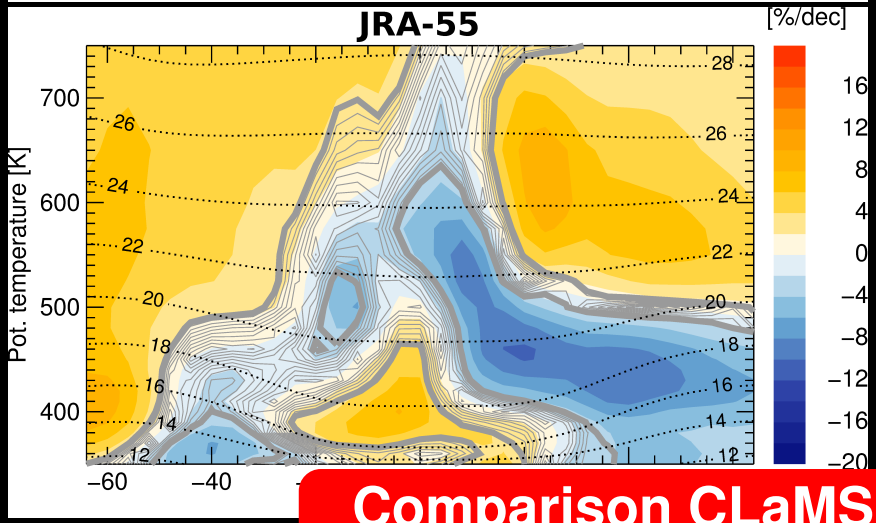
- age decrease in lowest stratosph. & SH stratosph.
- age increase in NH

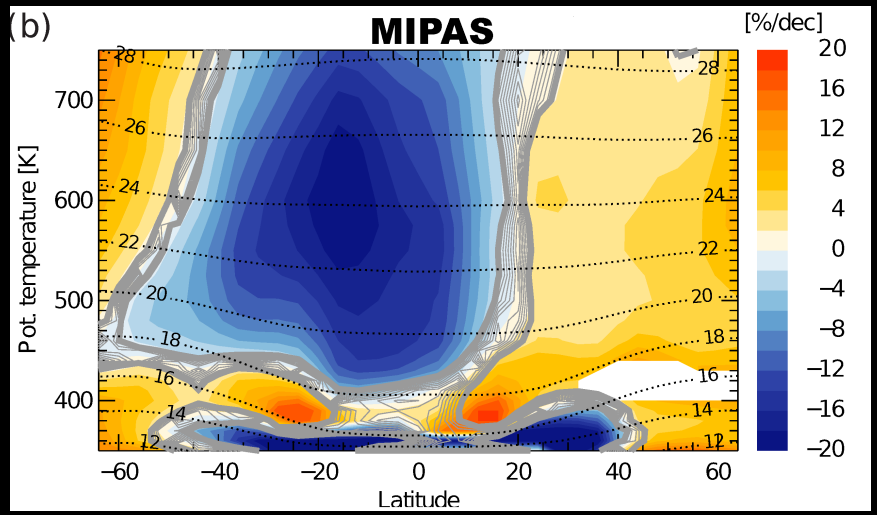
★ JRA-55: very different change-pattern!

Decadal trend 2002–12: CLaMS vs. MIPAS observations

MMM-MIP







★ Agreement CLaMS–MIPAS:

- age decrease in lowest stratosph. & SH stratosph.
- age increase in NH

★ JRA-55: v

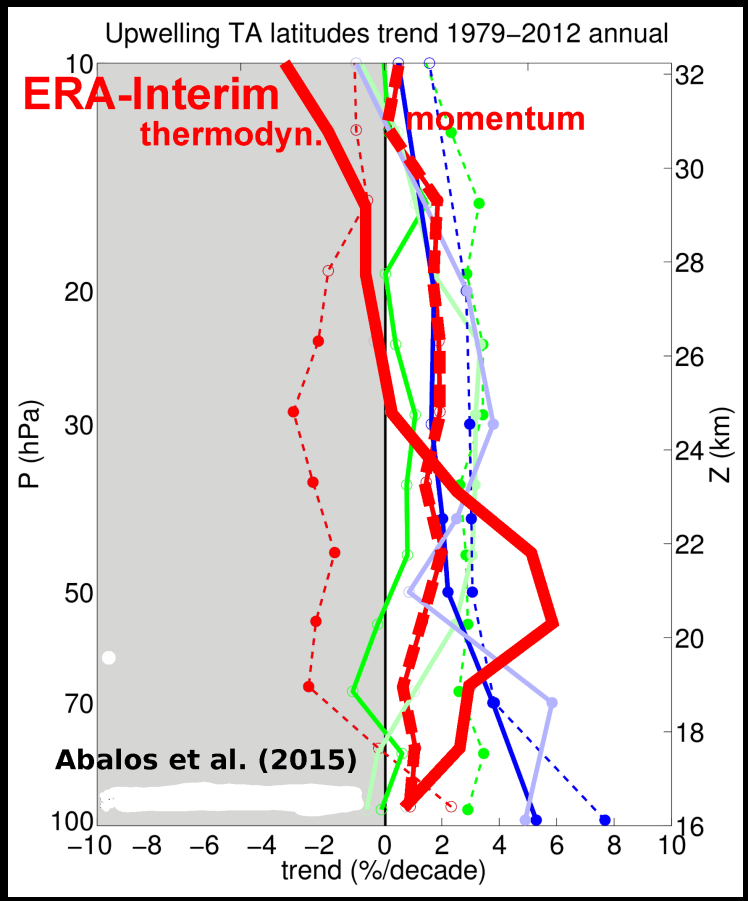
Comparison CLaMS age – MIPAS:

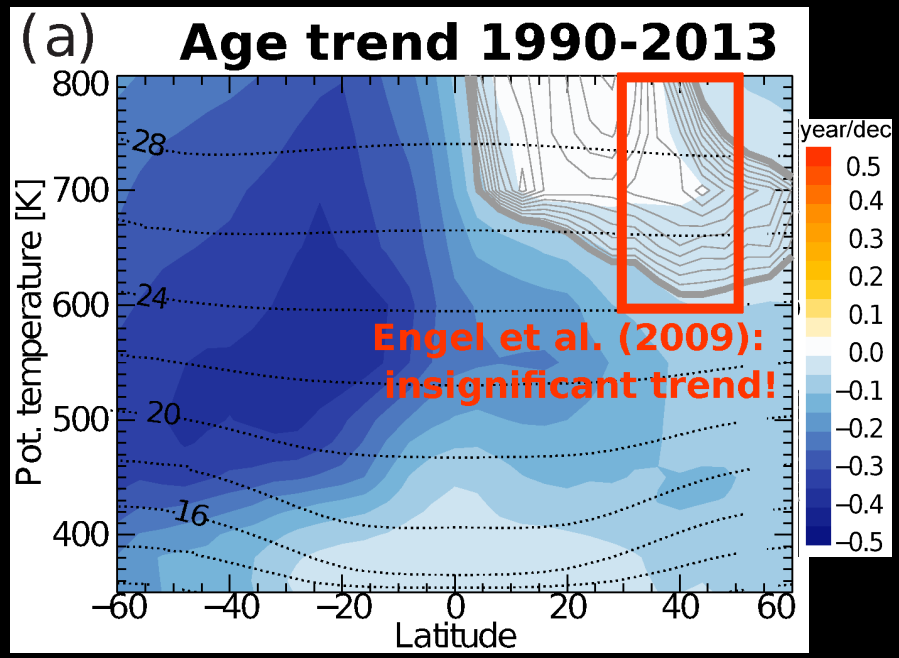
- climatology & variability: agreement for ERA & JRA!
- decadal trend: ERA agrees with MIPAS – JRA different!

⇒ What about long-term trends?

3. Mean age trends and mixing: ERA-Interim

★ Long-term trend: **BDC acceleration or deceleration?**



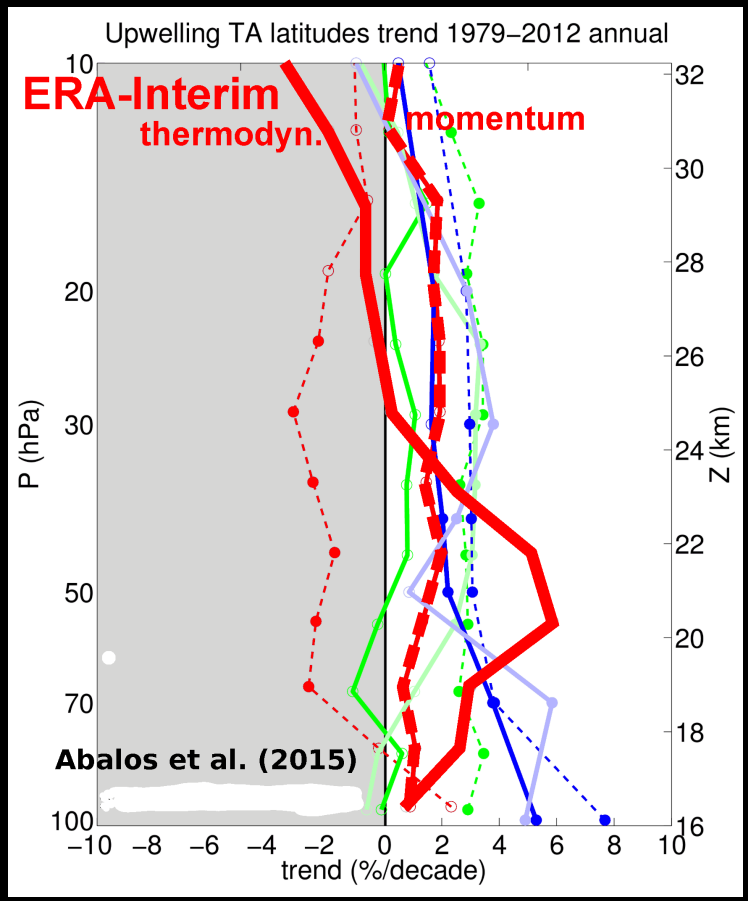


★ ...& age trends consistent with Engel et al. (2009)!

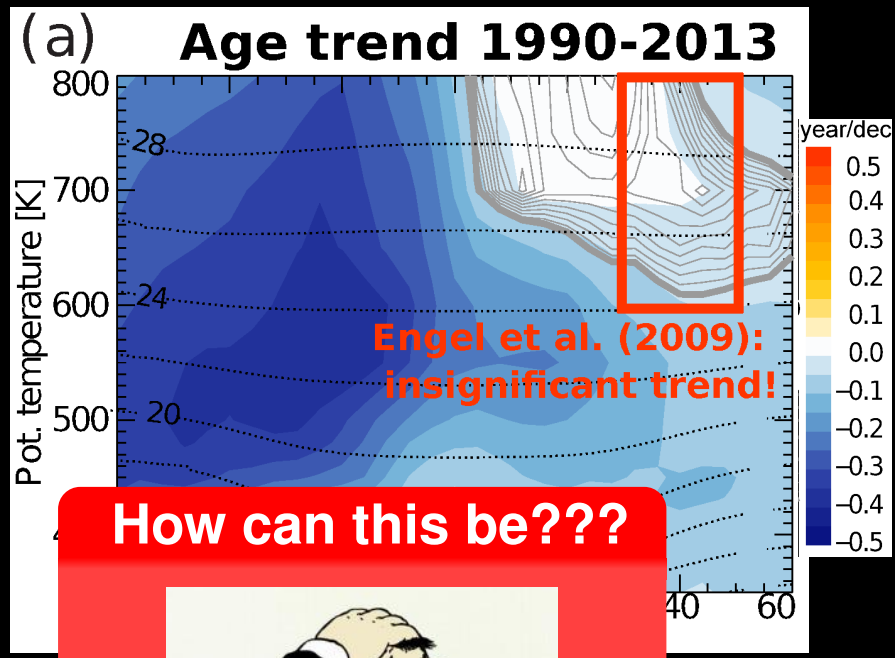
★ BDC-acceleration in ERA...

3. Mean age trends and mixing: ERA-Interim

★ Long-term trend: **BDC acceleration or deceleration?**



★ BDC-acceleration in ERA...



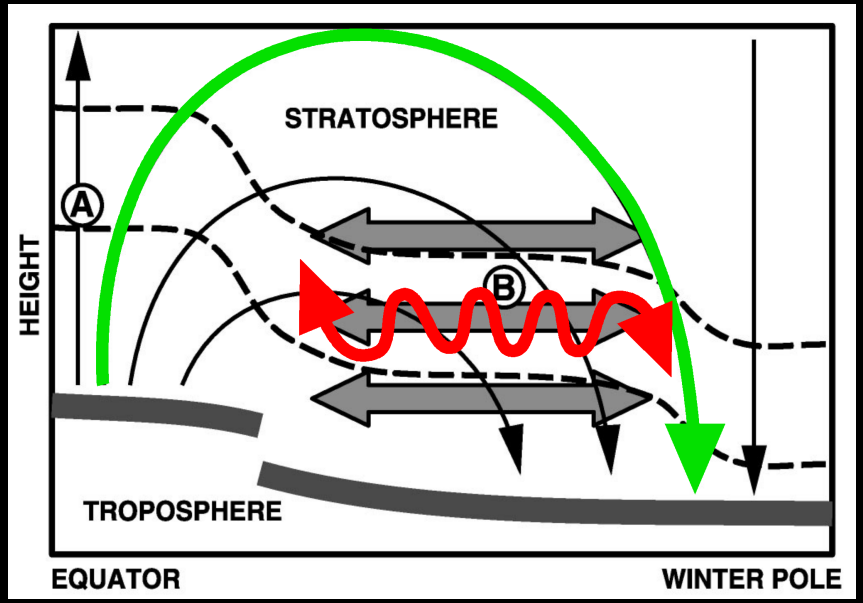
★ ...t with ...2009)!

How can this be???

⇒ **Mixing effect...!**

(Non-local) Analysis of resid. circulation & mixing

★ residual circulation → slow
isentropic eddy mixing → fast



★ integrate continuity eqn. along residual circulation: ($\overline{\Gamma}$ mean age)

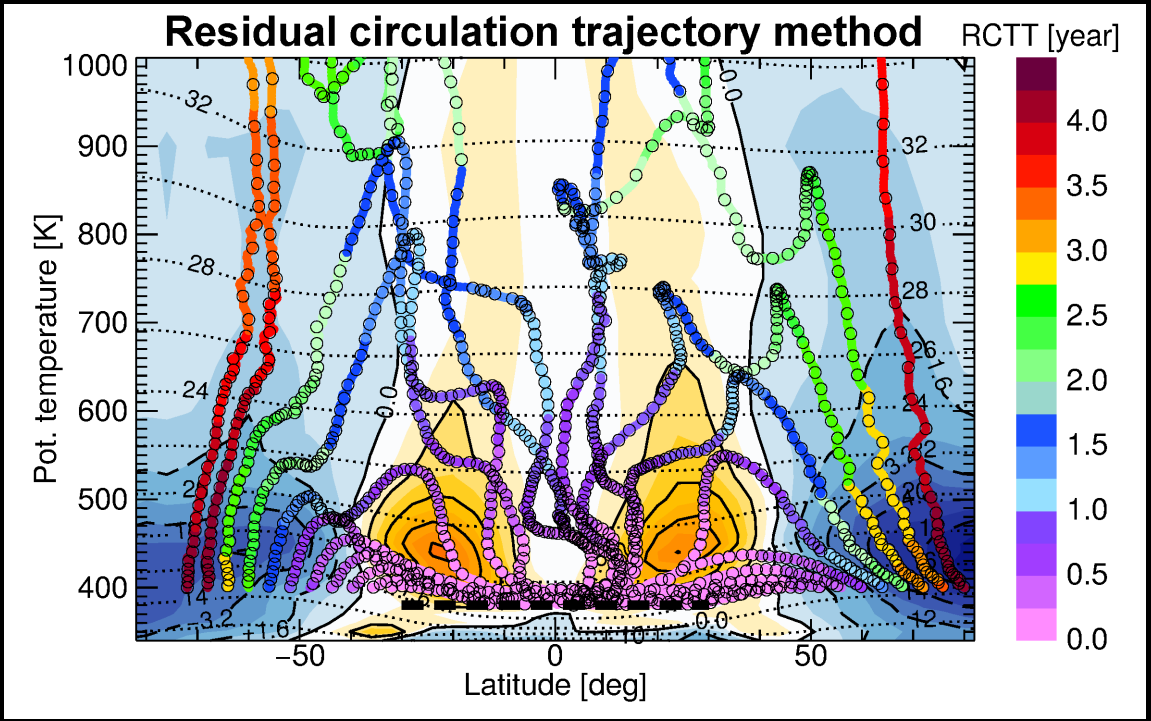
$$\partial_t \overline{\Gamma} \approx 1 - \overline{v}^* \partial_y \overline{\Gamma} - \overline{Q}^* \partial_\theta \overline{\Gamma} + \frac{1}{\sigma} \nabla \cdot \boldsymbol{M}_\Gamma$$

resid. circulation — eddy mixing

$$\overline{\Gamma} = \tau_{\text{RCTT}}(x,t) + \int_{t_0}^{t} \mathcal{M}(x,t)\, dt'$$

age = resid. circ. transit time + aging by mixing

(Non-local) Analysis of resid. circulation & mixing



★ integrate continuity eqn. along residual circulation:

$$\partial_t \overline{\Gamma} \approx \mathbf{1} - \overline{\mathbf{v}}^* \partial_y \overline{\Gamma} - \overline{\mathbf{Q}}^* \partial_\theta \overline{\Gamma} + \frac{\mathbf{1}}{\sigma} \nabla \cdot \boldsymbol{M}_\Gamma$$

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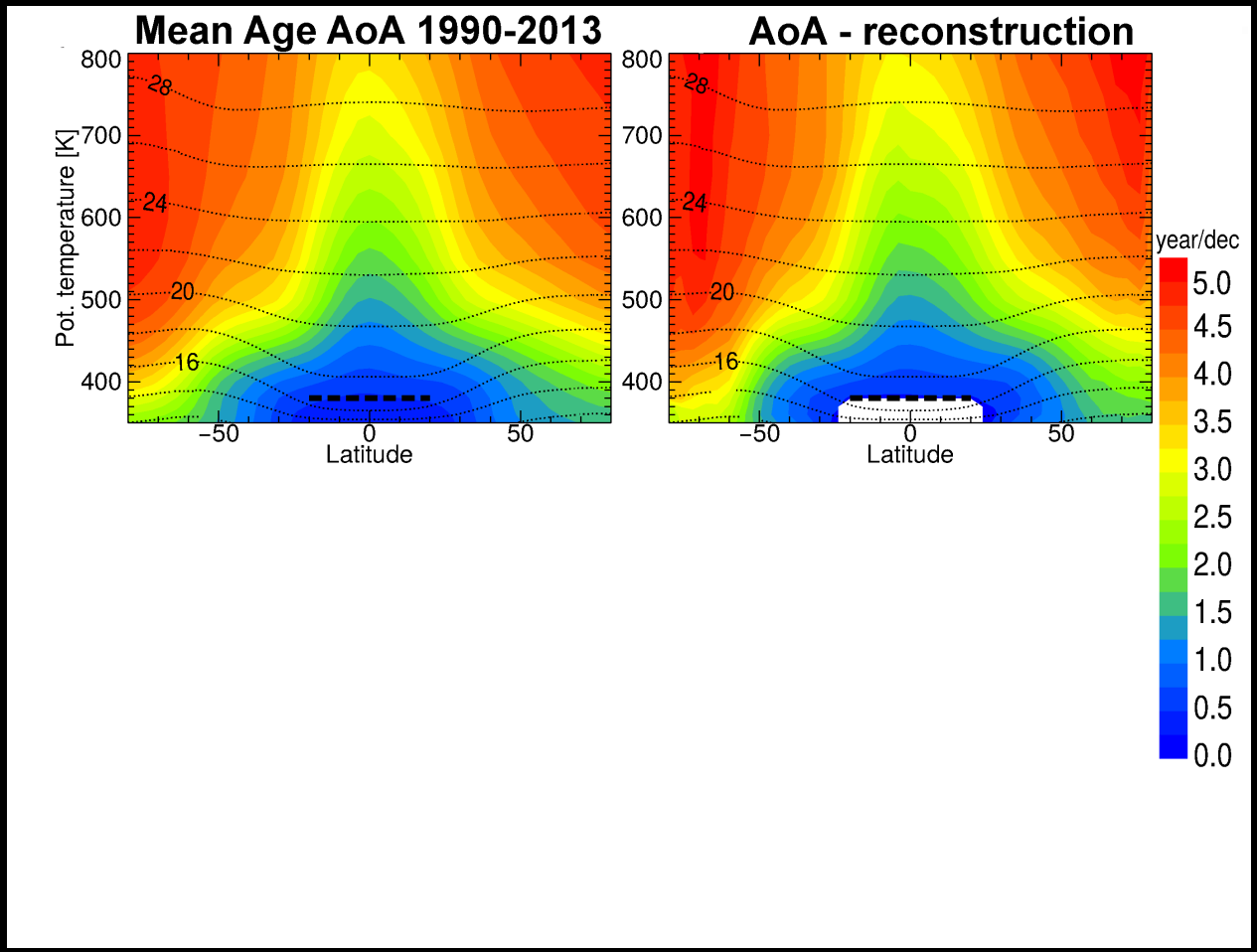
Effects of circulation & mixing on mean age

traj

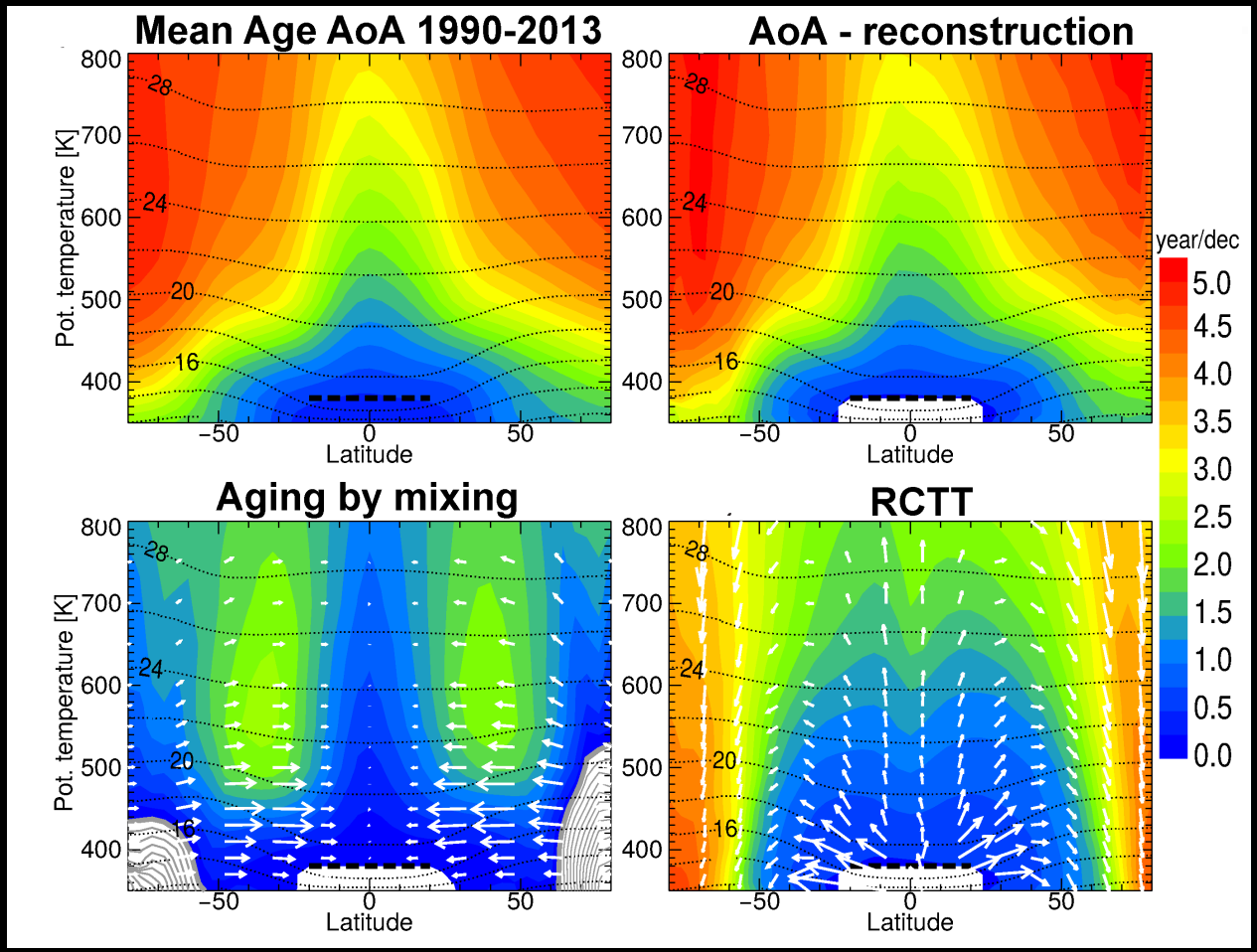


★ closed budget: age = resid. circ. transit time + aging by mixing

★

Effects of circulation & mixing on mean age

traj

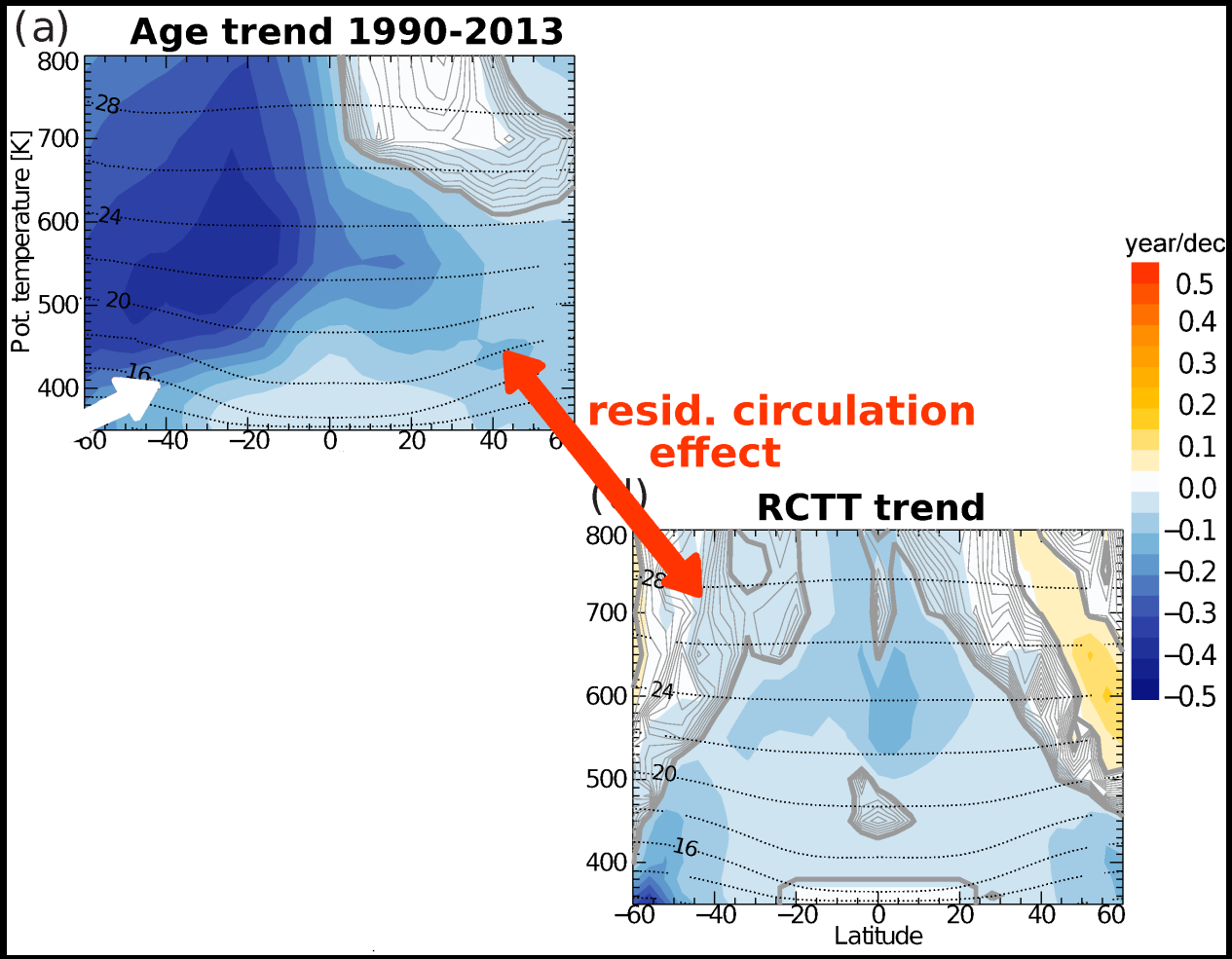


★ closed budget: age = resid. circ. transit time + aging by mixing

★ mixing causes global aging by recirculation (except polar lower stratosph.)

⇒ **“Aging by mixing”** [Garny et al., 2014]

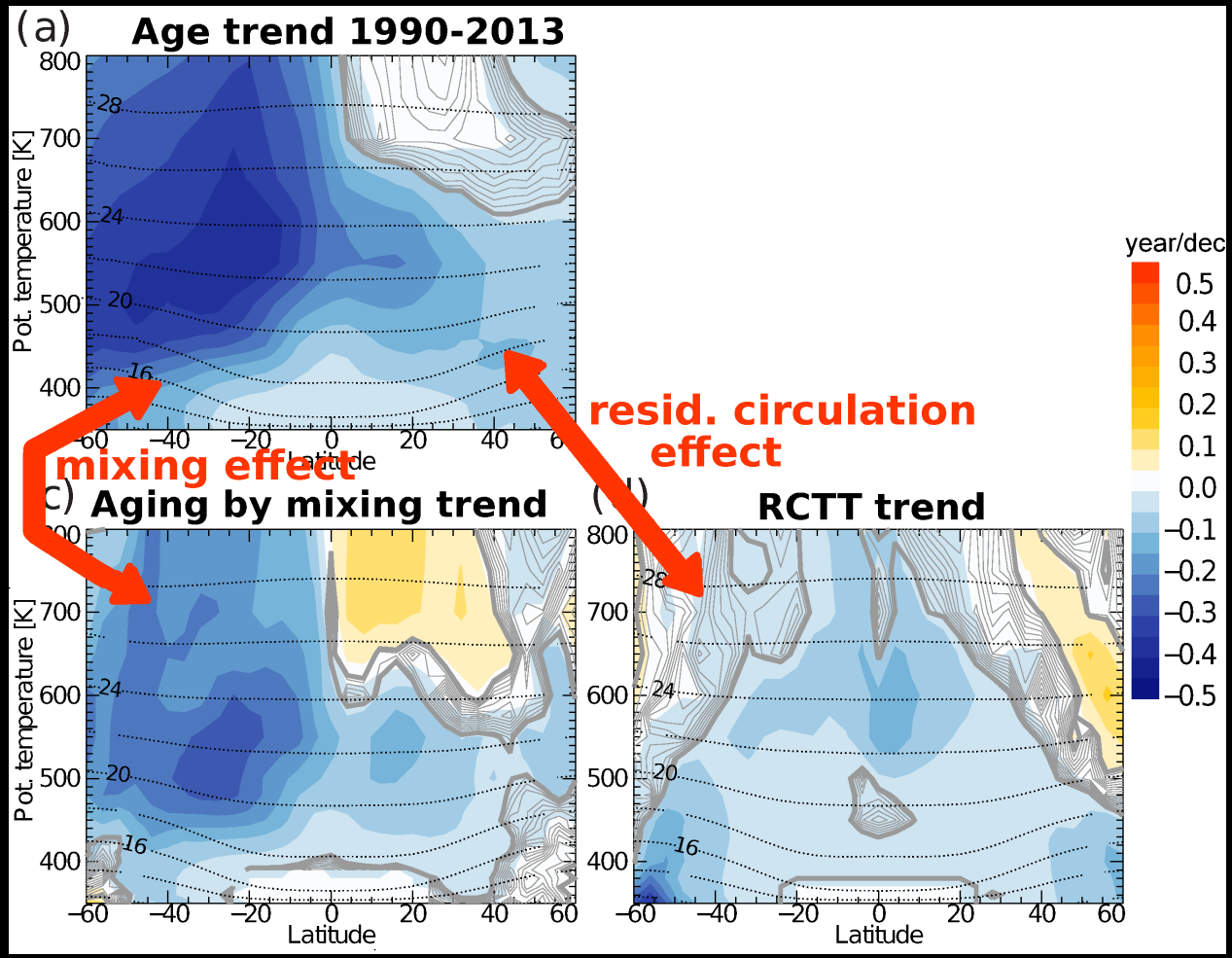
Trends 1990-2013: circulation & mixing



★ mixing crucial for mean age trend (even for decrease)!

★

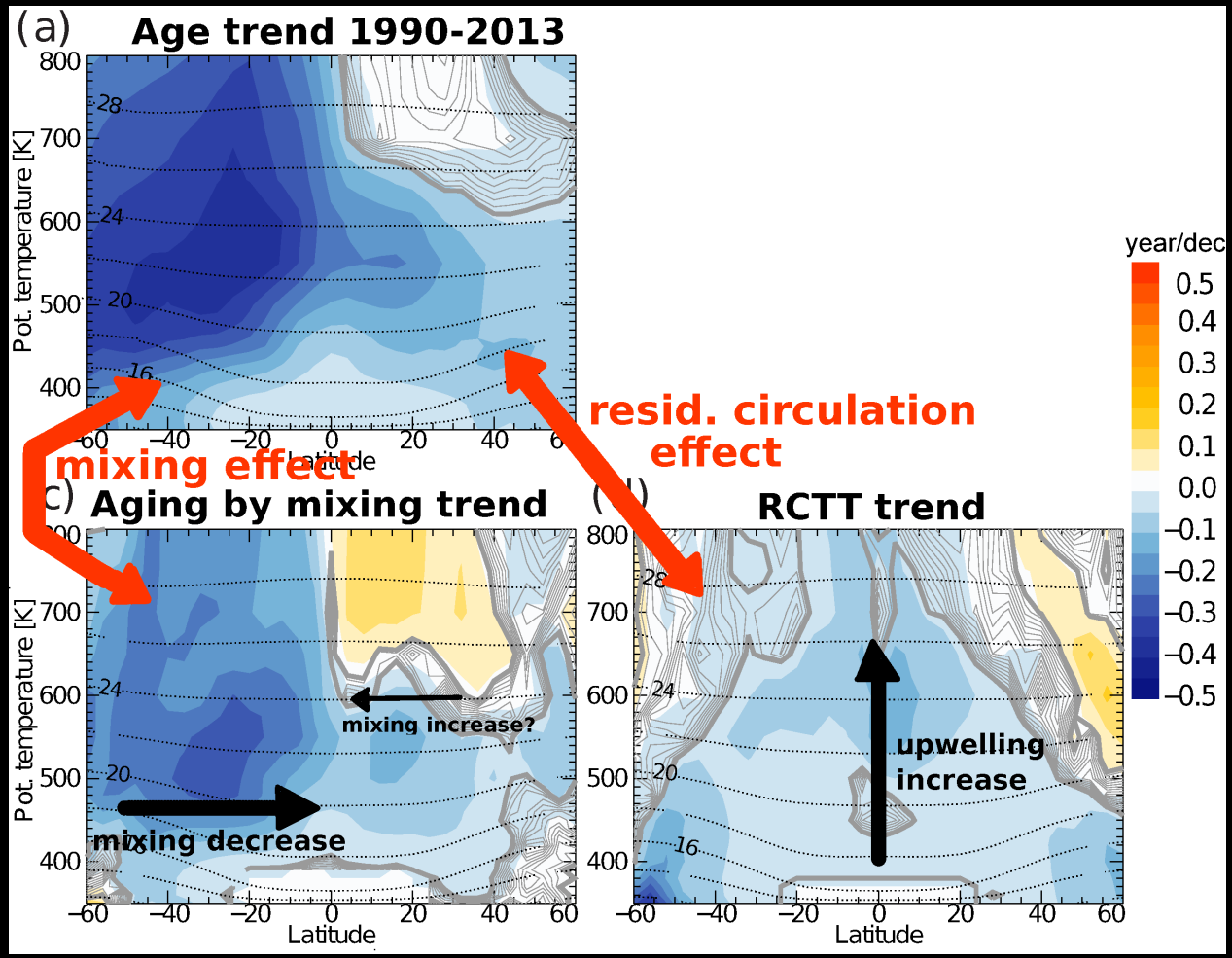
Trends 1990-2013: circulation & mixing



★ mixing crucial for mean age trend (even for decrease)!

★ resid. circulation acceleration & NH age increase possible!

Trends 1990-2013: circulation & mixing



★ mixing crucial for mean age trend (even for decrease)!

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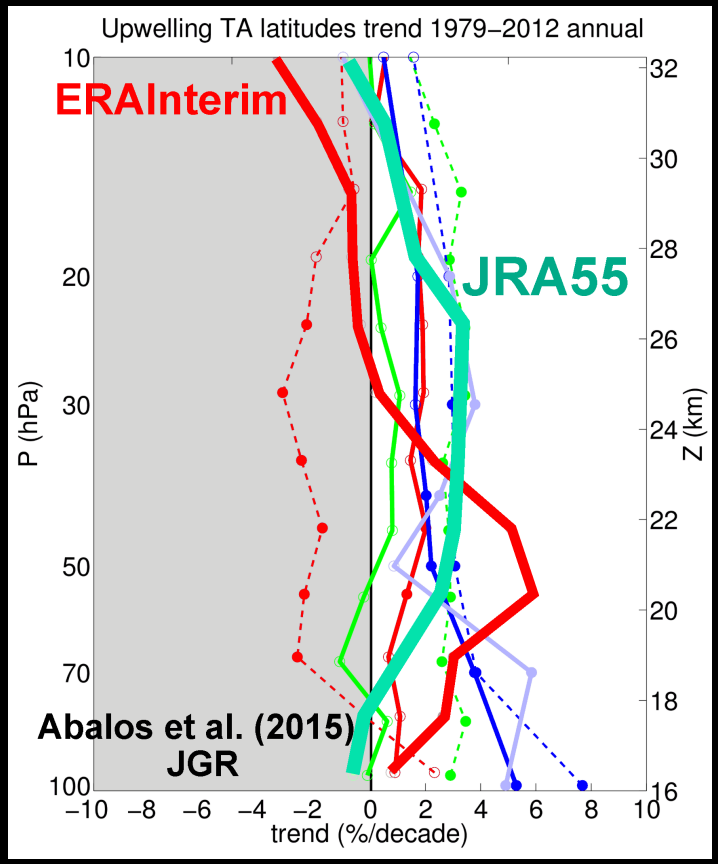
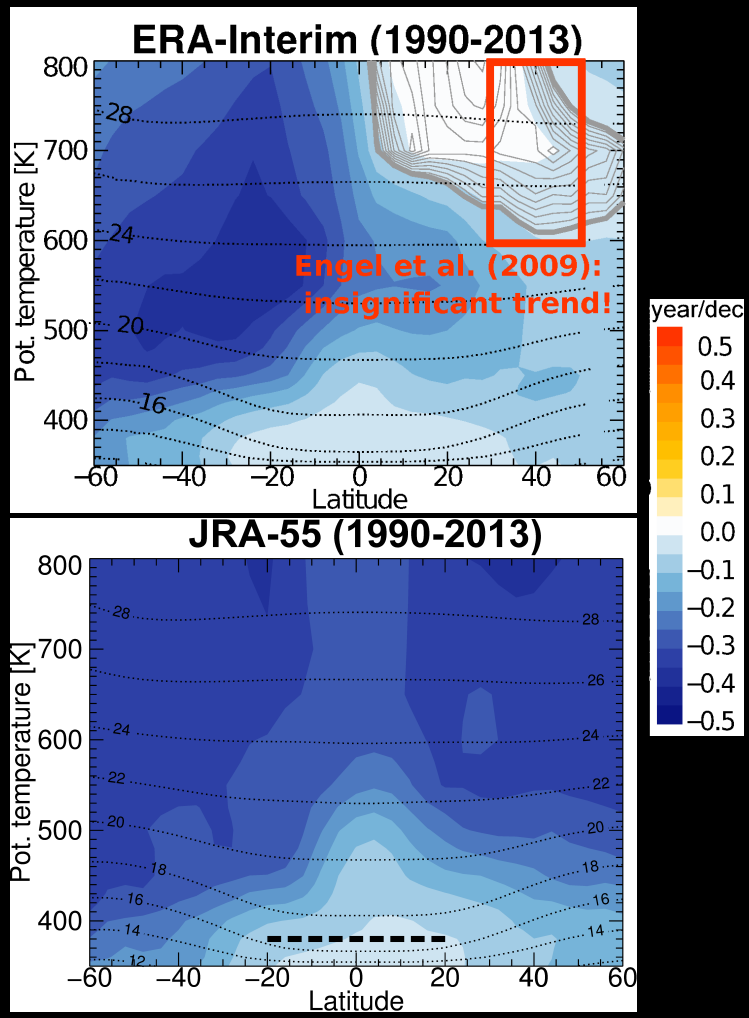
SH-mix

4. Mean age trends and mixing: ERA vs. JRA



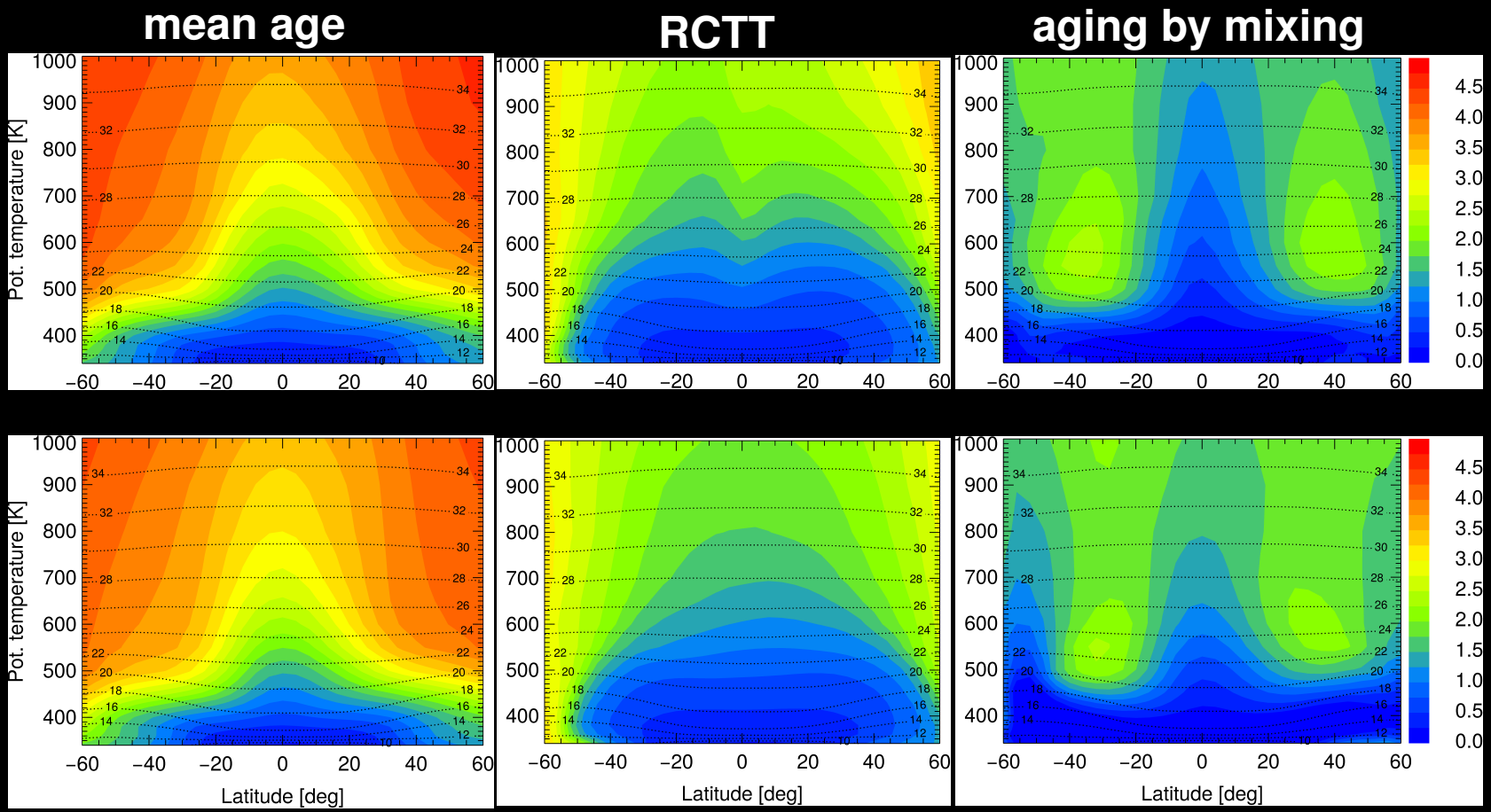


★ long-term evolution: upwelling increase & mean age decrease

★ ERA consistent with Engel et al. – JRA not!

Climatological circulation & mixing effects on mean age [yr]

diff

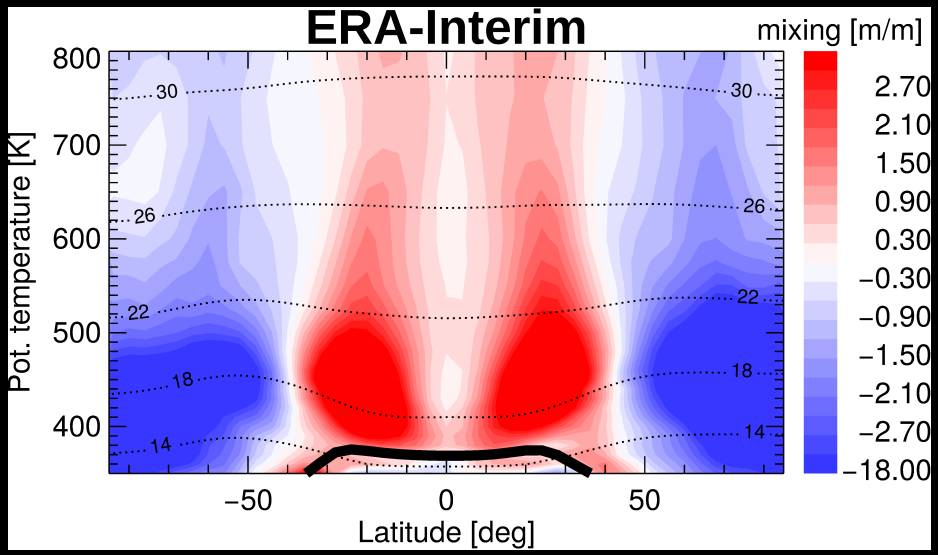


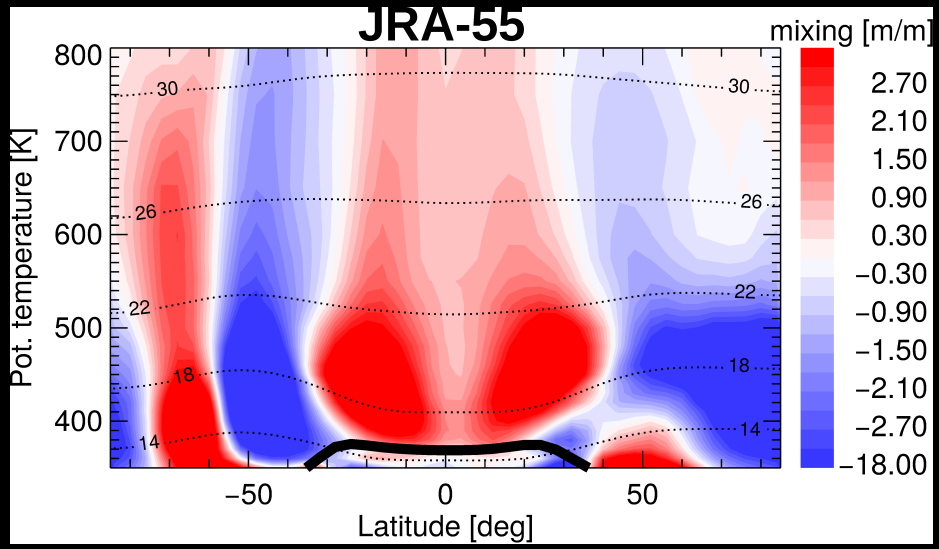
★ structural differences:

e.g., fastest resid. circulation in subtropics (ERA) ↔ tropics (JRA)

★ ERA: younger air in lower stratosphere & faster shallow resid. circ. branch!

Local mixing tendencies



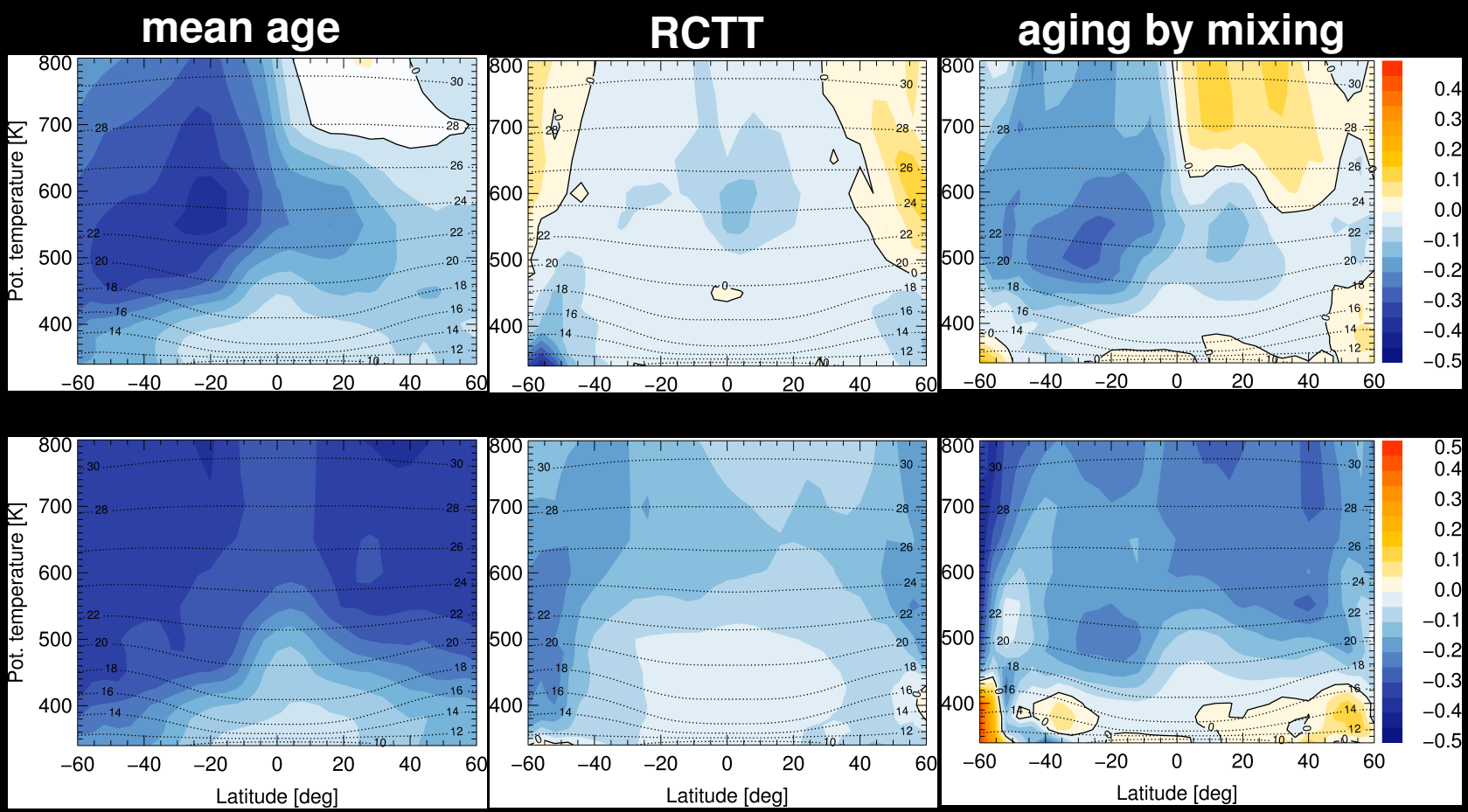


★ general: mixing increases age in tropics - decreases age in extratropics

★ difference in SH polar stratosphere (ERA $\leftrightarrow$ JRA)!

$\Rightarrow$ **Need for further study!**

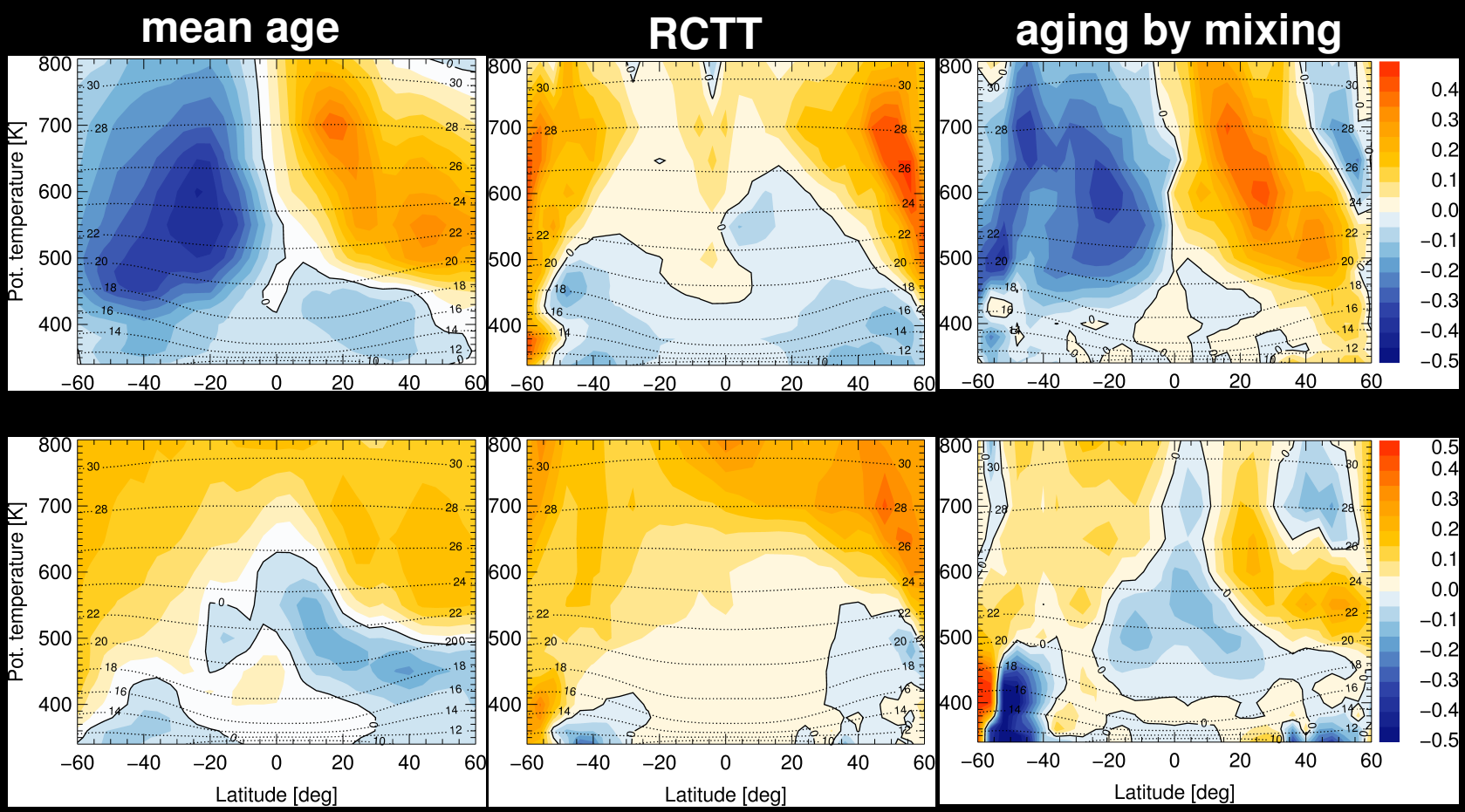
Trends of circulation & mixing effects 1990–2013 [yr/dec]



★ stronger resid. circulation acceleration above 22 km in JRA (see Abalos, 2015)!

★ JRA: negative mixing trend in NH ⇒ negative age trend, inconsistent with (Engel, 2009)!

Age, circulation & mixing trends 2002–2013



★ strong mixing effect differences ERA–JRA!

★ RCTT-trend: deep resid. circ. branch decelerates during last decade!

5. Conclusions

- ★ **Climatologically: CLaMS age agrees with observations (ERA & JRA)!**
- ★ **Long-term trends: age decrease**
  & residual circulation acceleration

  ...but: - ERA shows insignificant trend in NH $\gtrsim 24$ km [Engel et al., 2009] – JRA not!
  - JRA shows resid. circ. acceleration deeper into stratosphere!
- ★ **Decadal variability: ERA consistent with MIPAS (2002–12)**
  – JRA not!
- ★ **Mixing crucial for explaining mean age trends!**
- ★ **Difference in mixing effect ERA–JRA!**

BDC-change: long-term acceleration

Open question:

- structural changes in BDC?
- mixing impact (model differences)?
- decadal variability?

4. Conclusions

★ **Climatologically: CLaMS age agrees with observations (ERA & JRA)!**

★ **Long-term trends: age decrease** [Ploeger et al., 2015]
& residual circulation acceleration [Abalos et al., 2015]

...but: - ERA shows insignificant trend in NH $\gtrsim 24$ km [Engel et al., 2009] – JRA not!
- JRA shows resid. circ. acceleration deeper into stratosphere!

★ **Decadal variability: ERA consistent with MIPAS (2002–12)** [Stiller et al., 2012]
– JRA not!

★ **Mixing crucial for explaining mean age trends!**

★ **Difference in mixing effect ERA–JRA!**

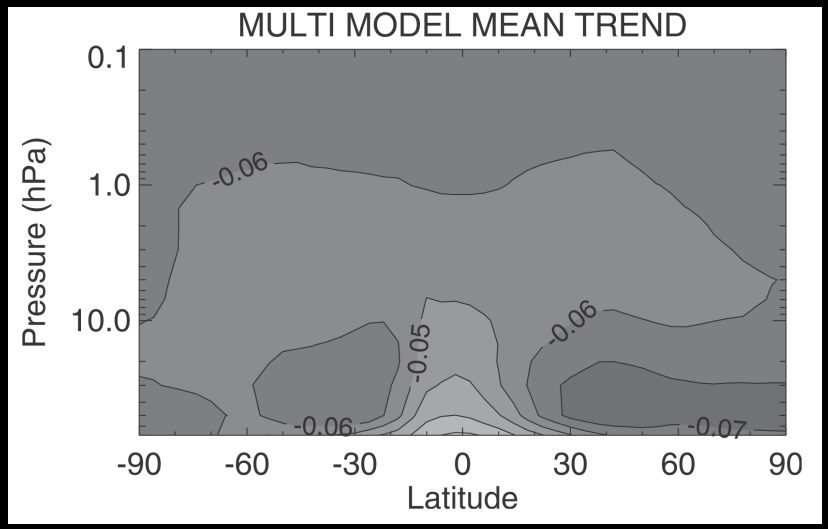
BDC-change: long-term acceleration

Open question:

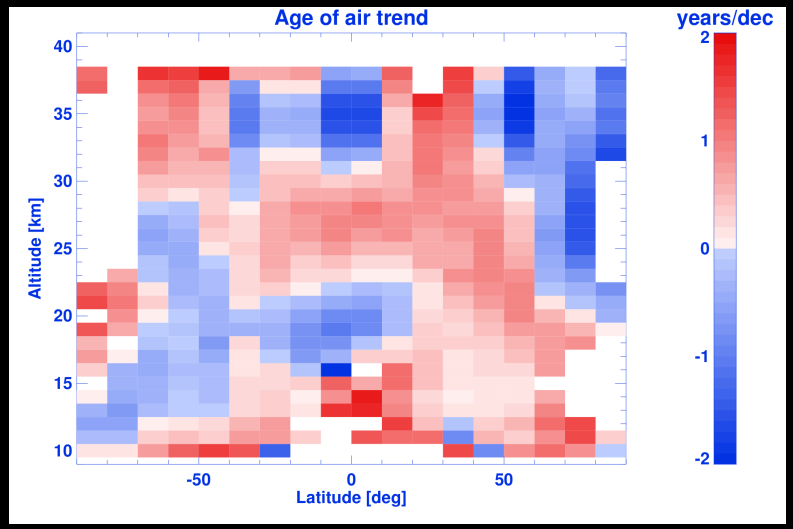
- structural changes?
- mixing impact (model differences)?
- decadal variability?

Appendix

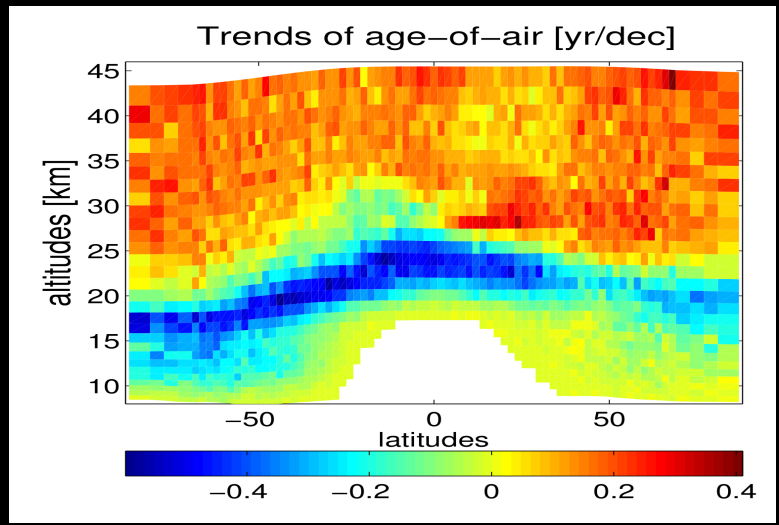
Multi-model mean [Butchart et al., 2010]



MIPAS observ. (2002-2010) [Stiller et al., 2012]



Backtrajectories (1989-2010) [Diallo et al., 2012]

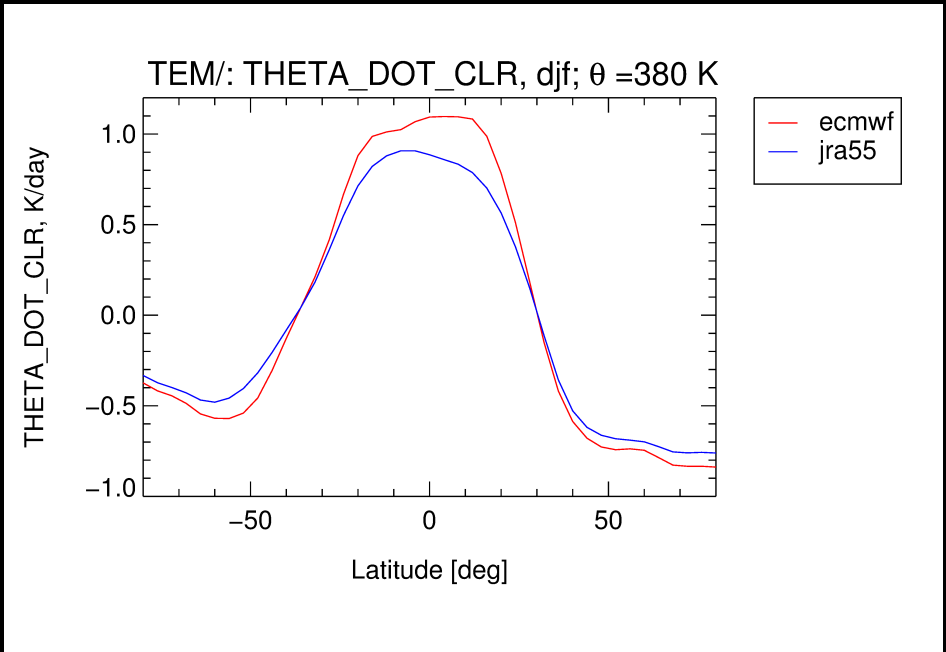


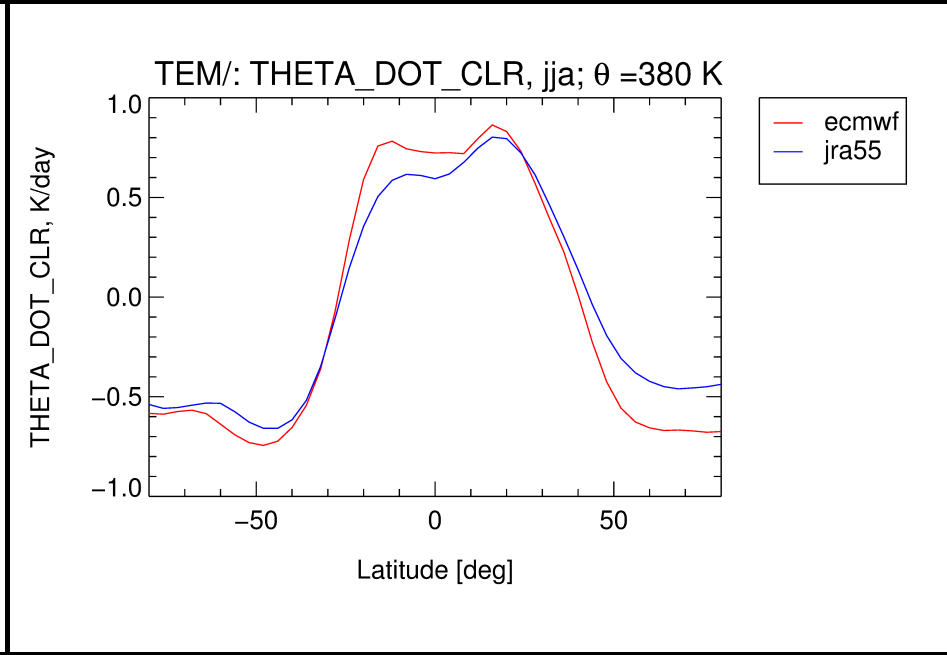
Observations vs. models:

⇒ totally different trends (sign, pattern,...)!

Diabatic vertical velocity at 20 km

▸ age-comp

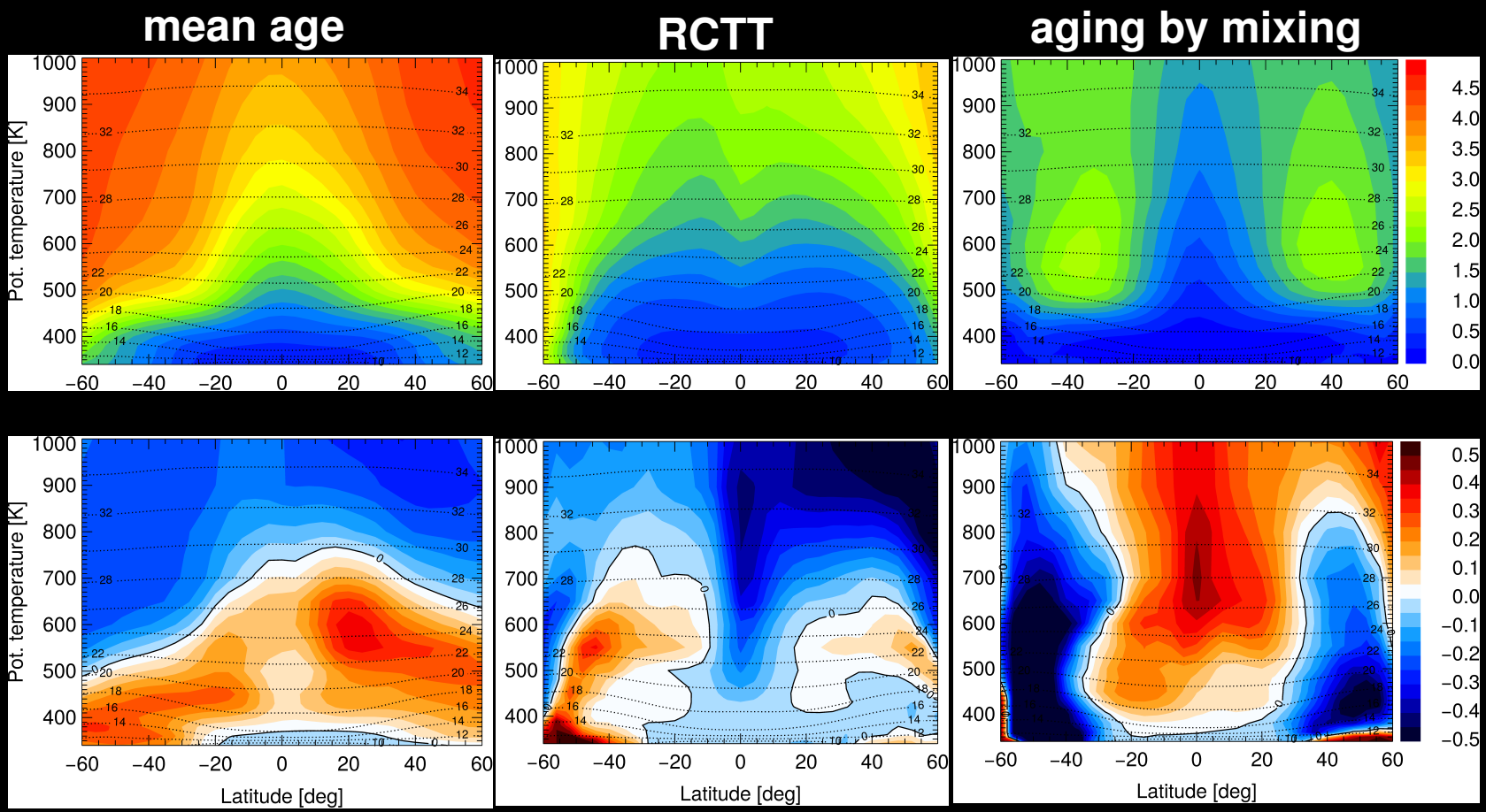




★ stronger tropical upwelling and extratropical downwelling for ERA!

Differences of circulation & mixing: JRA – ERA

rc-mix

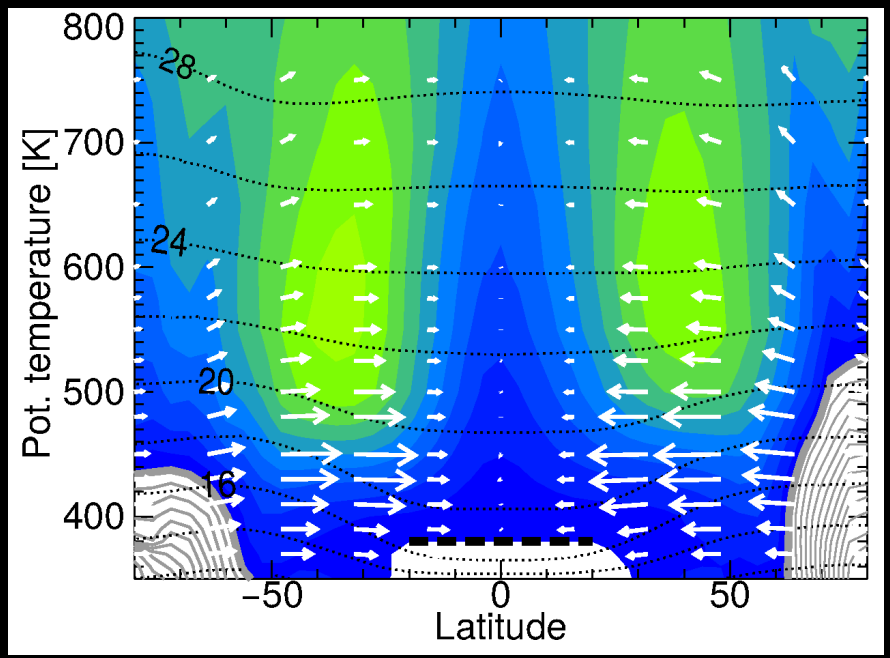


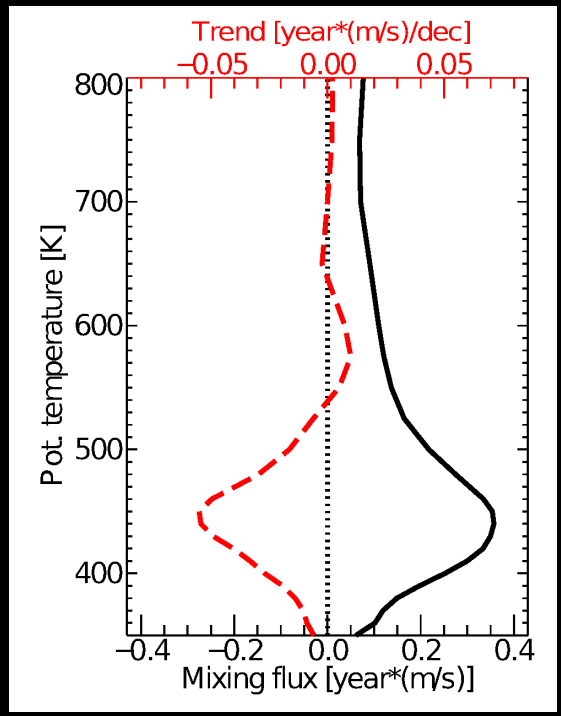
★ ERA: younger air in lower stratosphere
& faster shallow residual circulation branch
& stronger mixing effect in mid-latitude lower stratosphere

★ ...but: large residual → unresolved effects?

SH mean age decrease due to weakening mixing:

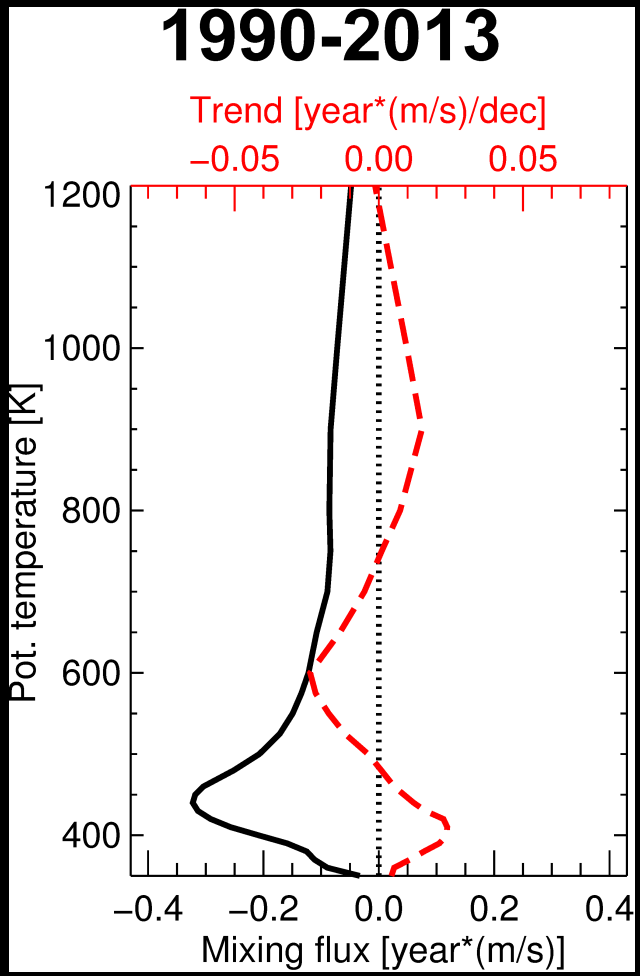
★ Local mixing flux (arrows) & ... across 30°S (profile)

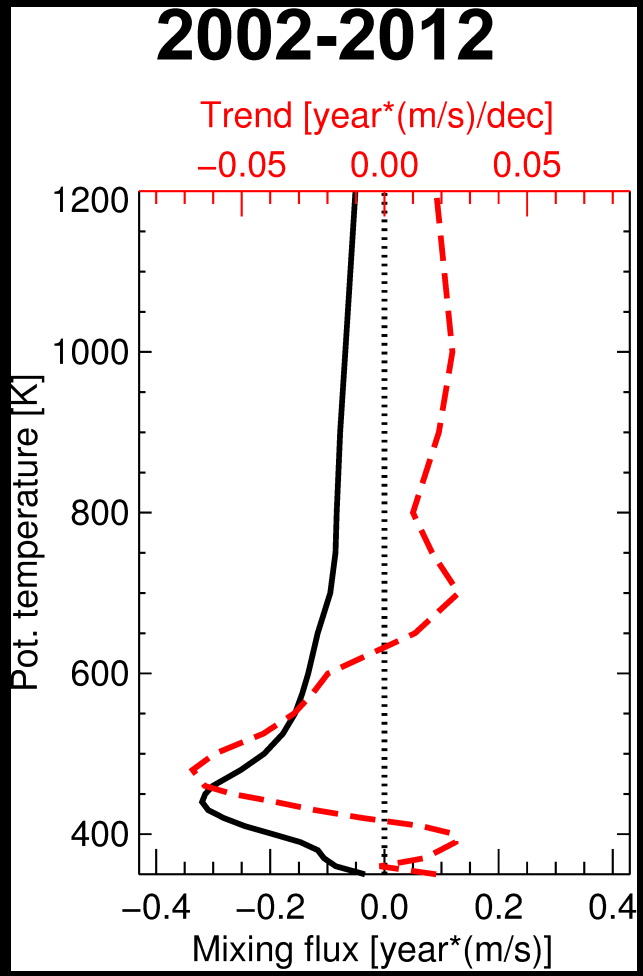




★ SH lower stratosphere: weakened mixing ⇒ age decrease!

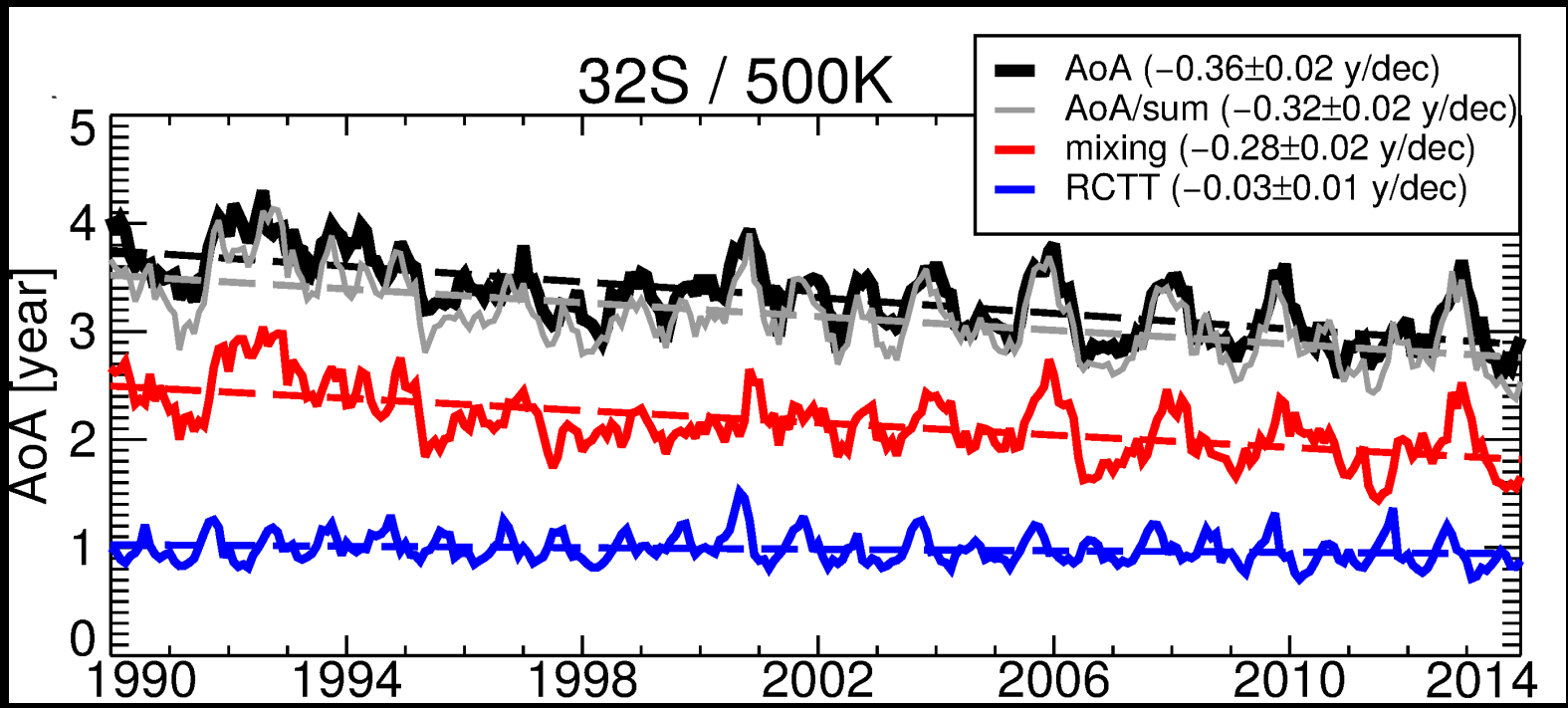
Local mixing flux trends in NH subtropics (across 30N)





★ mixing increase below ≈500K & mixing decrease above!

Effects of circulation & mixing on mean age



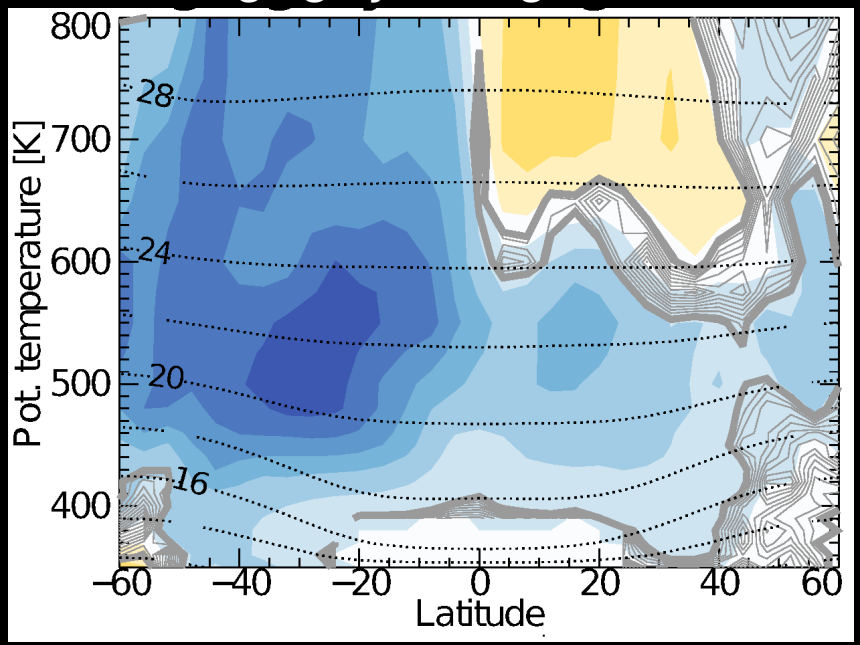
- ★ SH lower stratosphere: mean age decrease
- ★ interannual variability & trend related to mixing

Are mixing trends coupled to resid. circulation or independent?

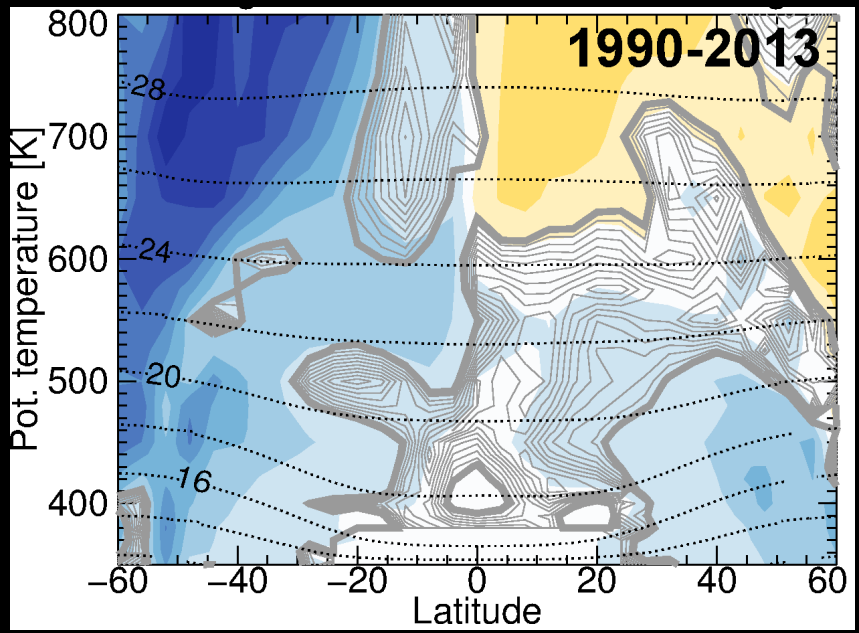
★ Aging by mixing trend: A) local mixing (diffusivity)
B) transit time (RCTT)
C) circulation pattern

★ Sensitivity study (const. local mixing)

Aging by mixing trend



...with const. mixing



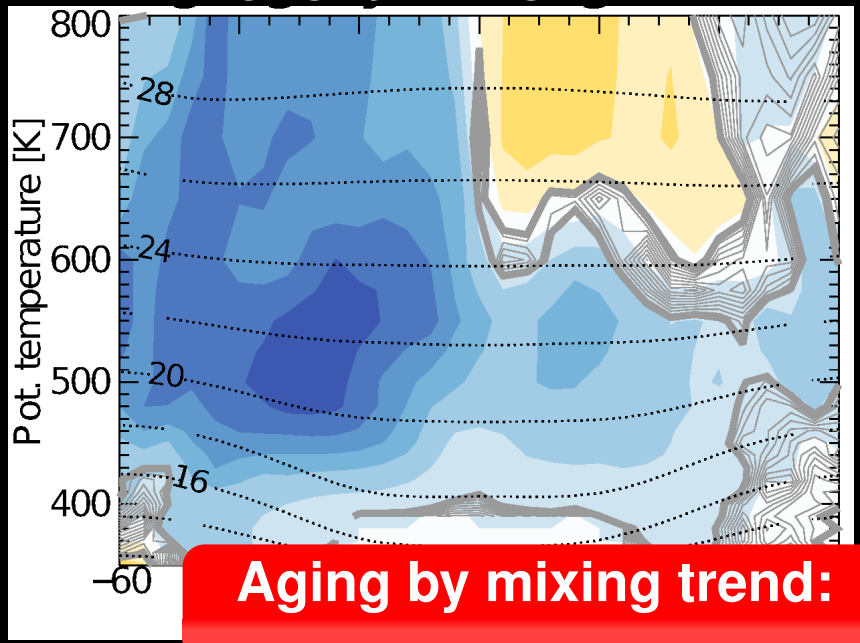
★ Const. mixing calculation reconstructs trend above ≈550K

Are mixing trends coupled to resid. circulation or independent?

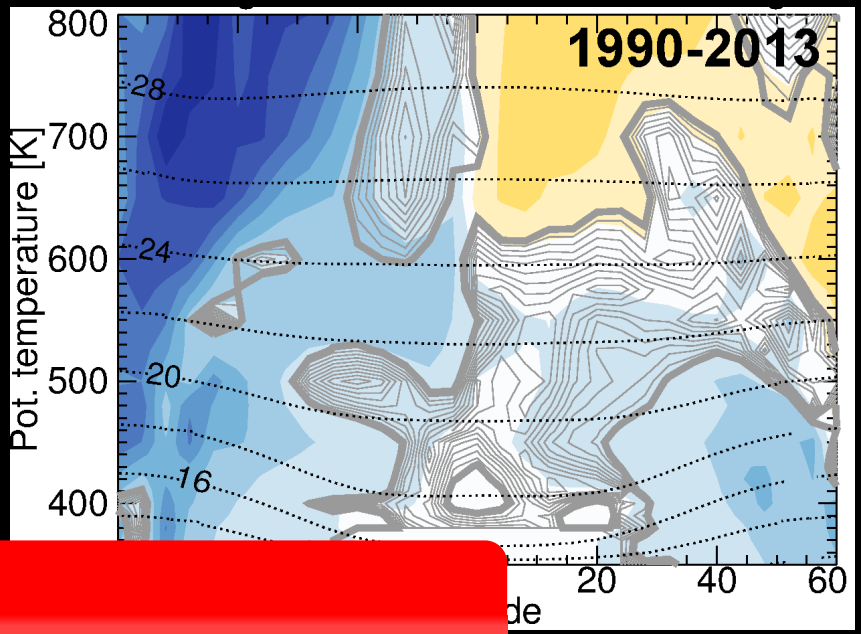
★ Aging by mixing trend: A) local mixing (diffusivity)
B) transit time (RCTT)
C) circulation pattern

★ Sensitivity study (const. local mixing)

Aging by mixing trend



...with const. mixing



★ Const

Aging by mixing trend:

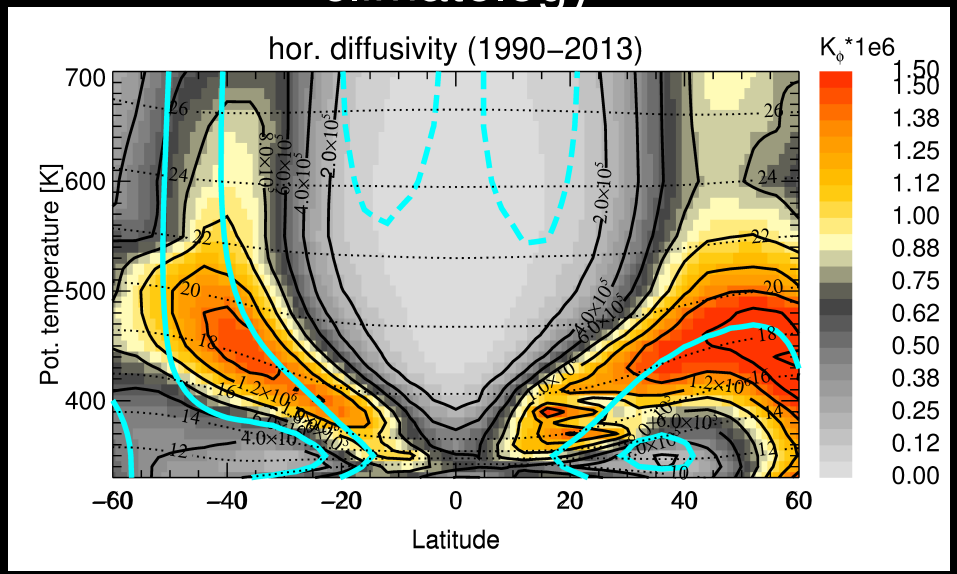
- above ≈550K coupled to resid. circulation
- below from local mixing trend

Diffusivity from flux-gradient relationship

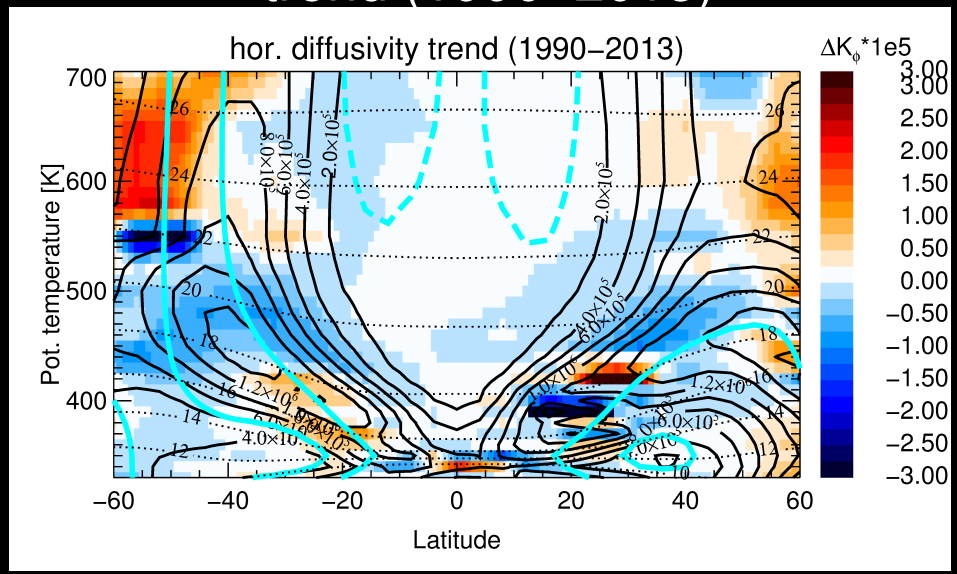
★ Diagnose Diffusivity K from

hor. mixing flux $\approx$ K · hor. age gradient

climatology

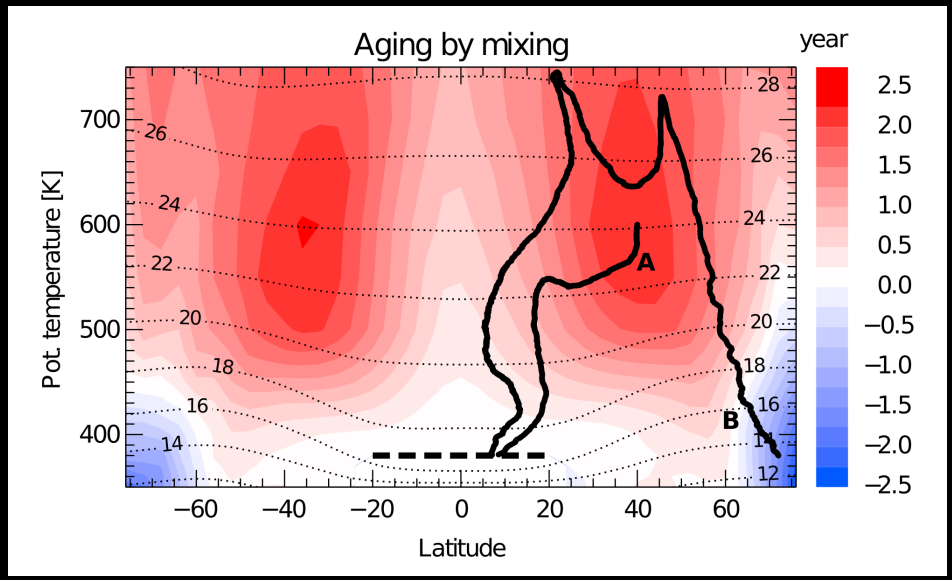


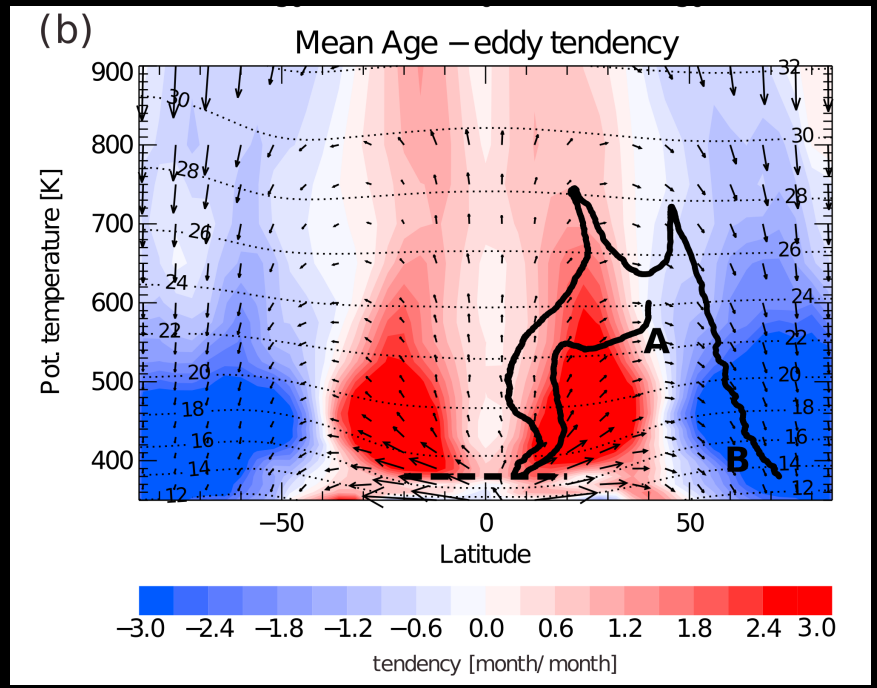
trend (1990–2013)



Negative aging by mixing?

back





★ Negative aging by mixing: negative local mixing & pathway!