Long-term changes in the Brewer-Dobson Circulation: the role of the residual circulation and mixing

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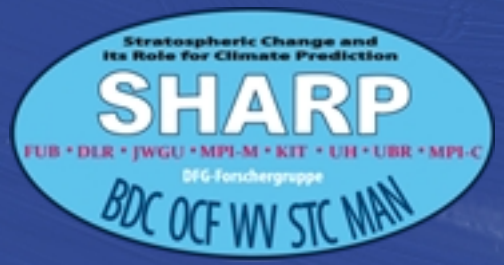
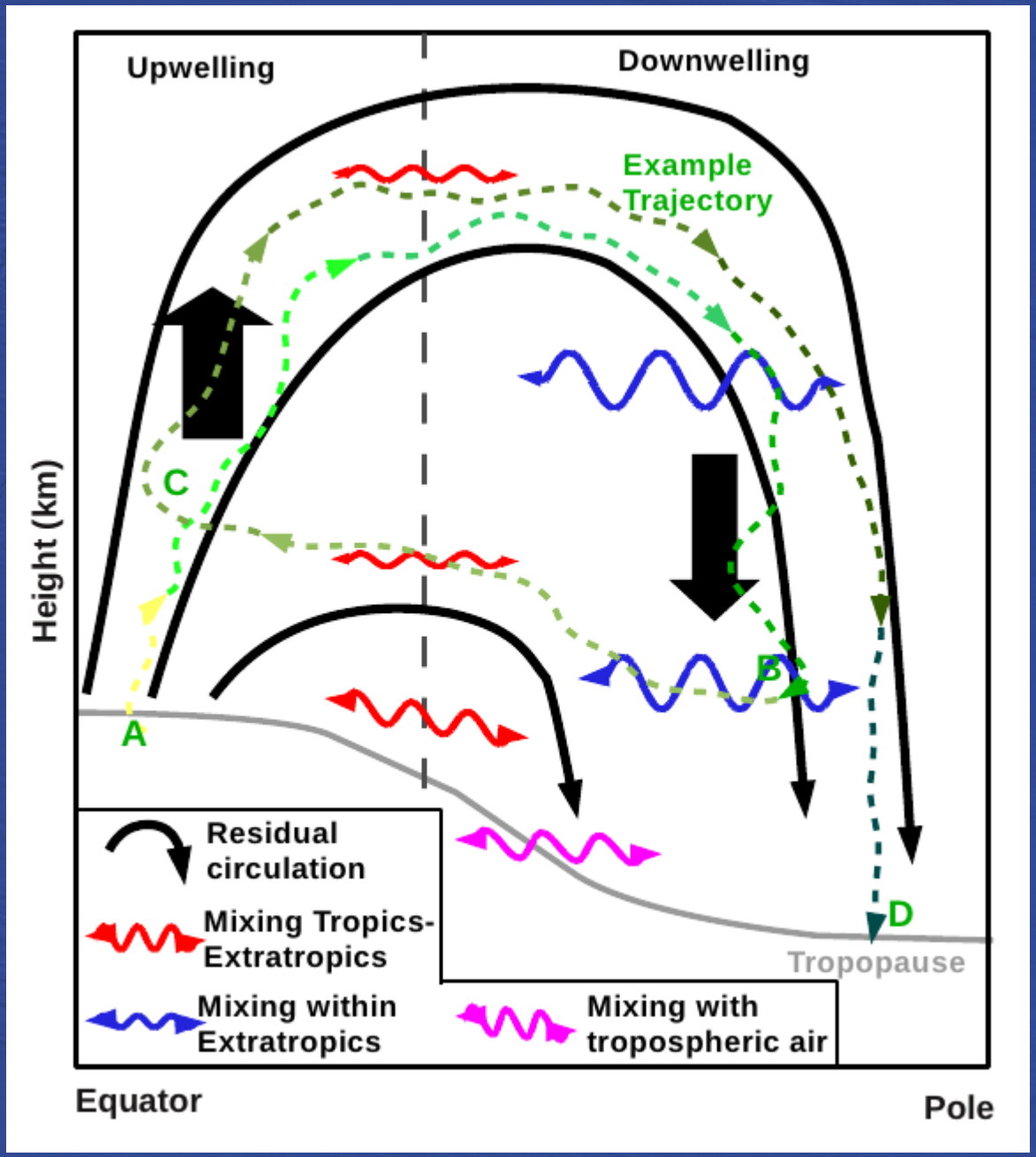


The Brewer-Dobson Circulation: Residual circulation + "Mixing"

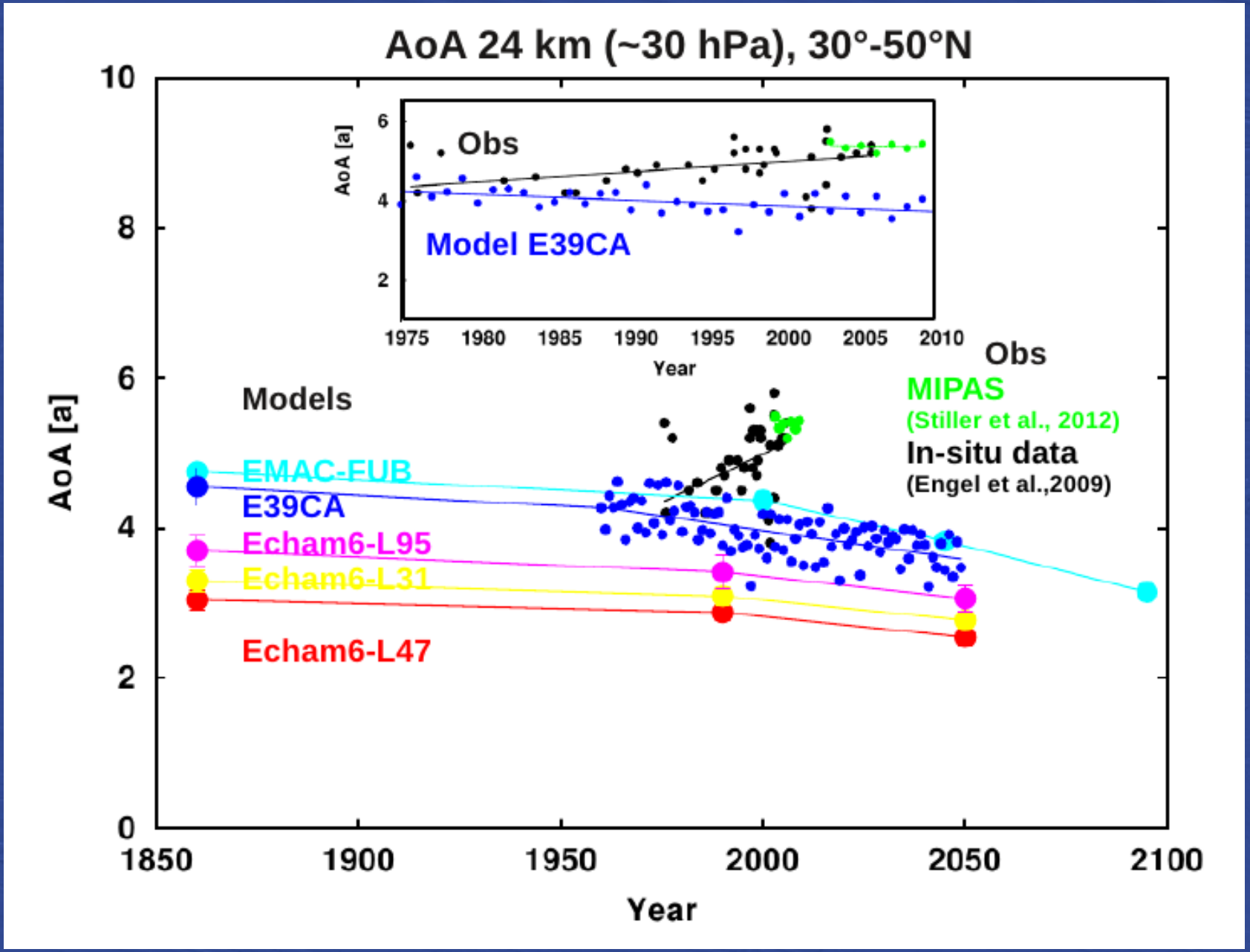


BDC is full transport circulation:

"Residual circulation" (=net mass transport) + "mixing" (=two-way mass transport)

Measure of the transit time of an air parcel through the stratosphere: "Age of Air"

Long-term changes in the BDC - Models and Observations



Data from various SHARP groups

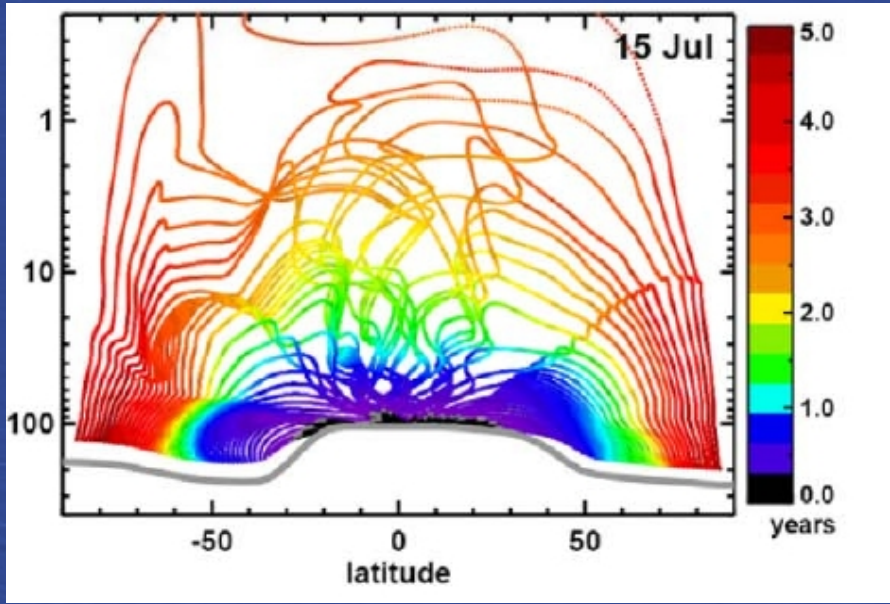
How can we quantify the effects of “mixing” on Age of Air ?

Age of Air → residual circulation transport + effects of “Mixing”

How to distinguish the two?

→ use “Residual circulation Transit time (RCTT)” (Birner&Bönisch 2011):

hypothetical “age” if there was only transport by the residual circulation



From Birner & Bönisch, 2011

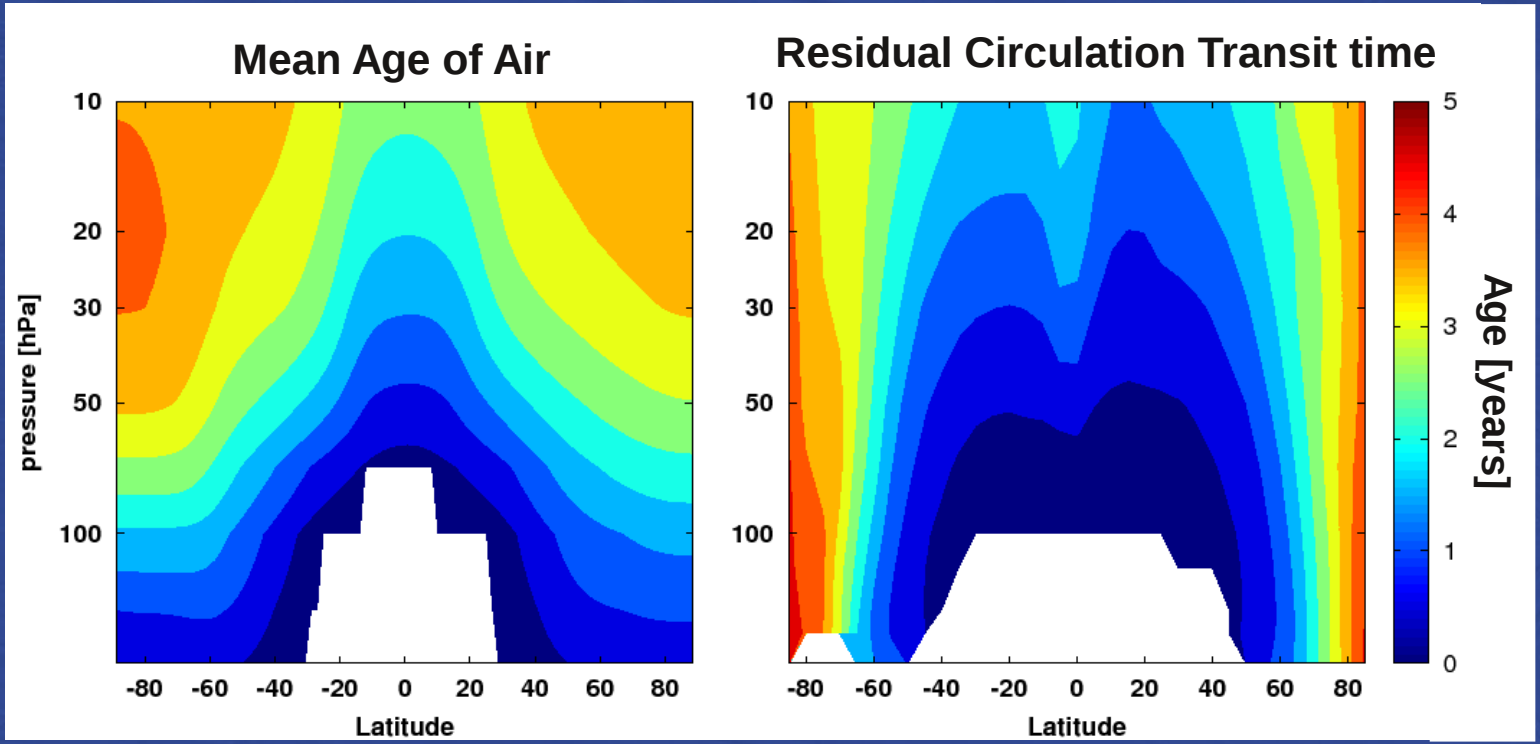
- calculate backward trajectories driven by the residual winds (v*, w*) in the latitude-pressure plain.

- terminate where trajectories hit the tropopause. The time elapsed is the 'transit time' at the location the trajectory was started.

Age of Air and RCTT from Model data

Calculate 'Residual Circulation Transit time' (RCTT) from global Model

→ allows comparison with Age of Air

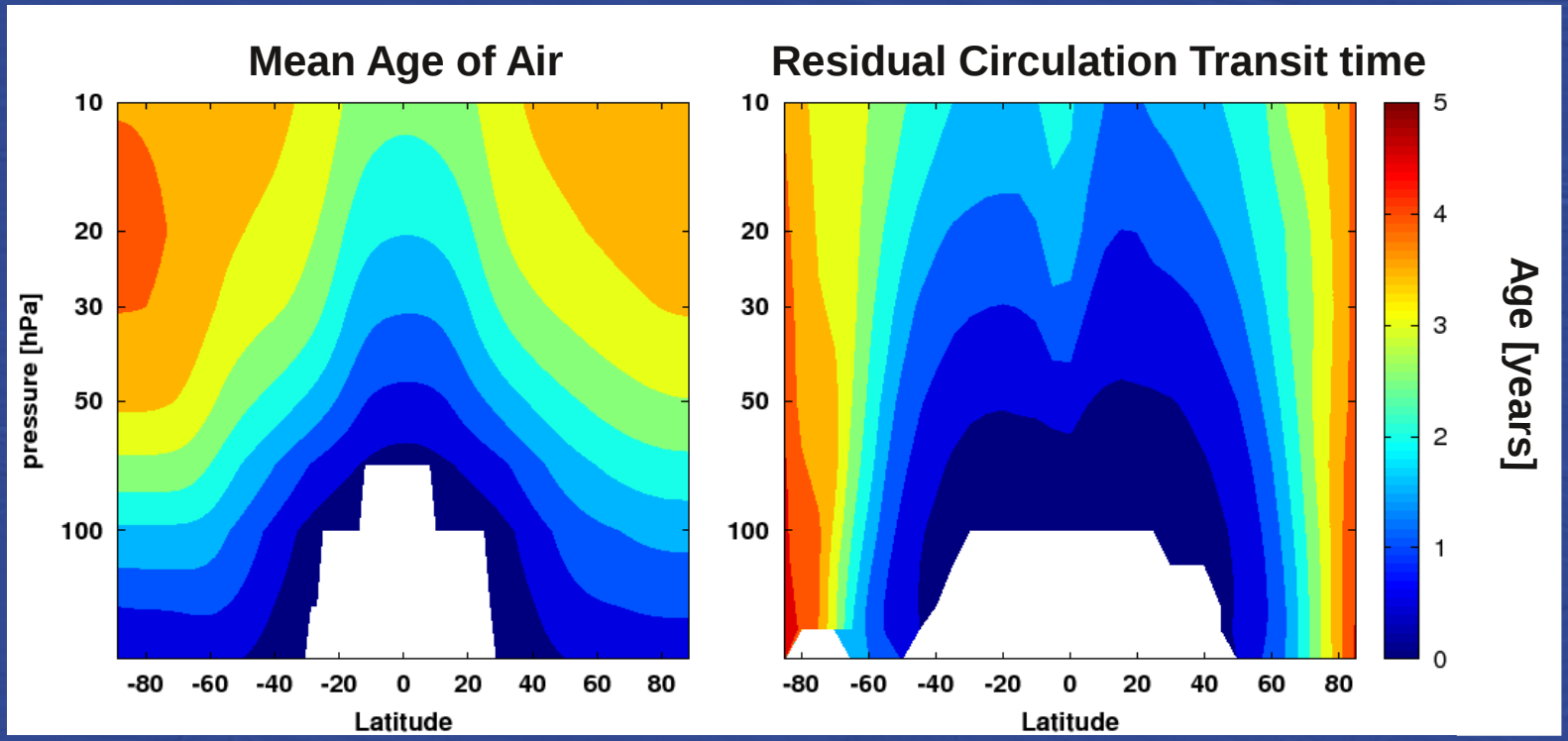


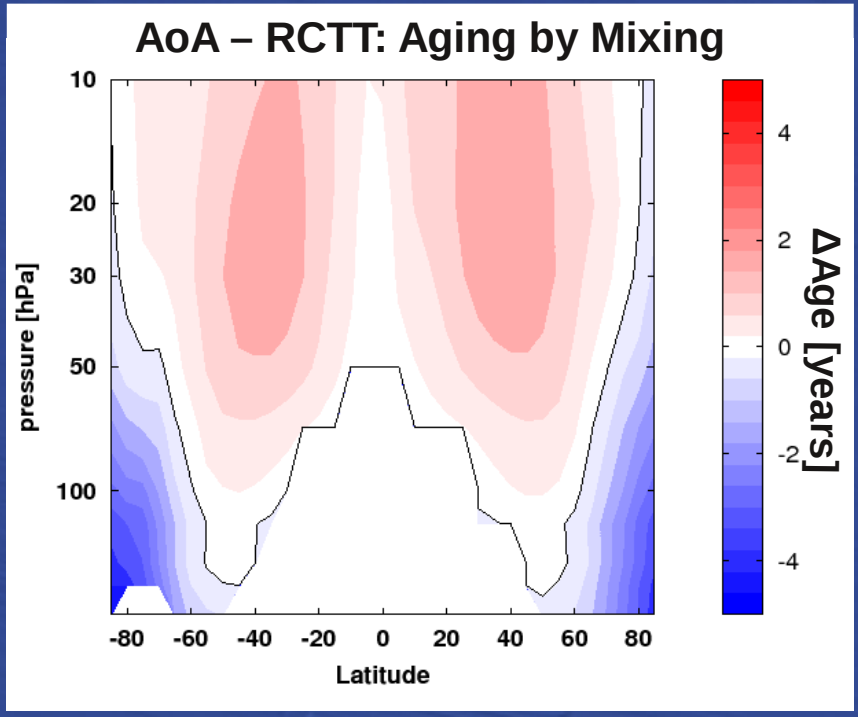
Echam6 time-slice simulation, 10 year annual mean (simulations by F. Bunzel)

AoA calculated from linear tracer

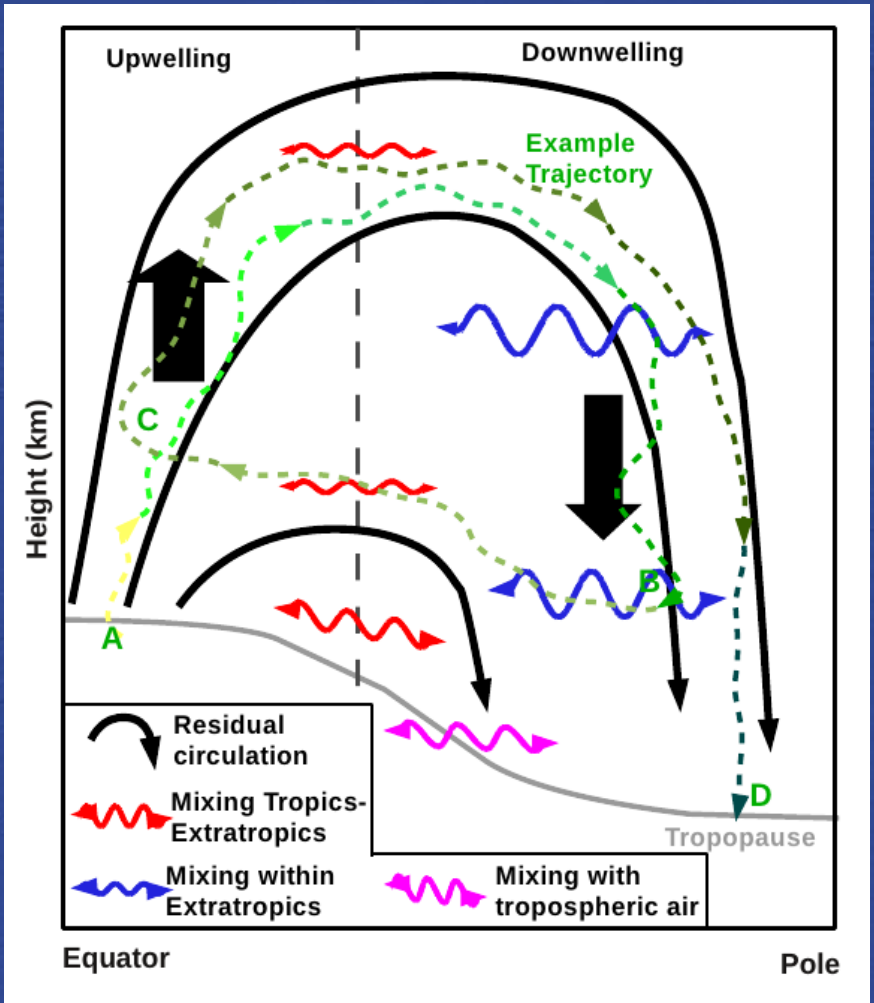
RCTT calculated from 2D trajectories driven by the resid. circ. (v*,w*) only

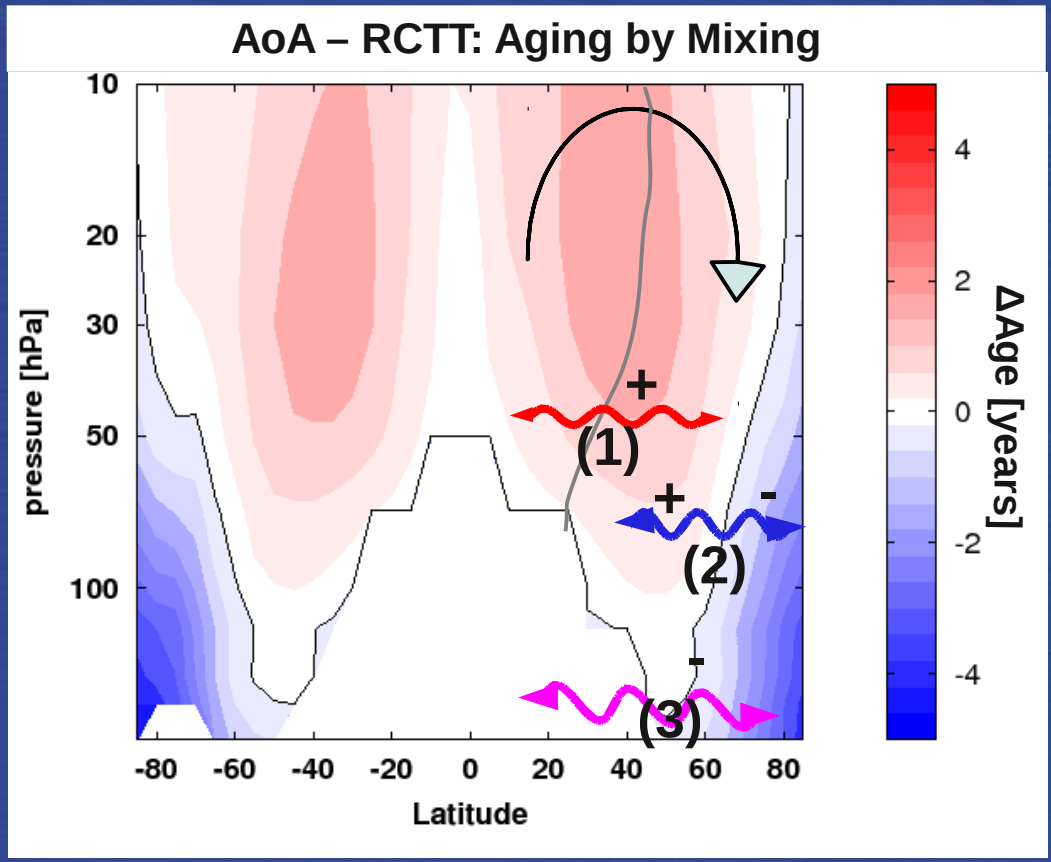
Difference Age of Air and RCTT: Aging by Mixing





How can we explain “Aging by mixing”?





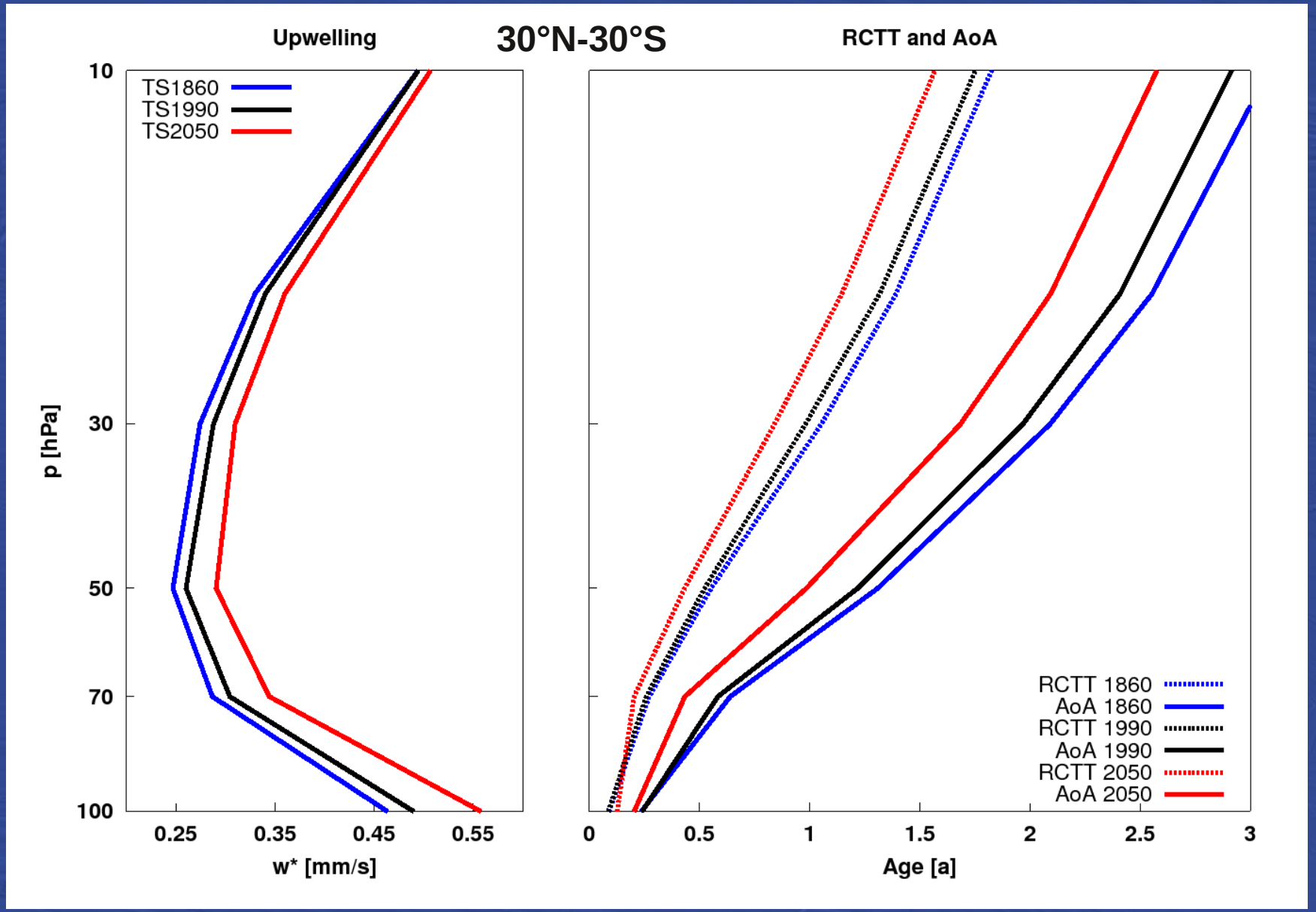
1. Mixing between up- and downwelling region leads to increased AoA above the mixing level due to the “re-circulation” of air parcels

2. Mixing within the extratropics flattens the AoA gradient there, but has little effect in the mean

3. Mixing in the lowermost stratosphere with tropospheric air causes AoA to decrease

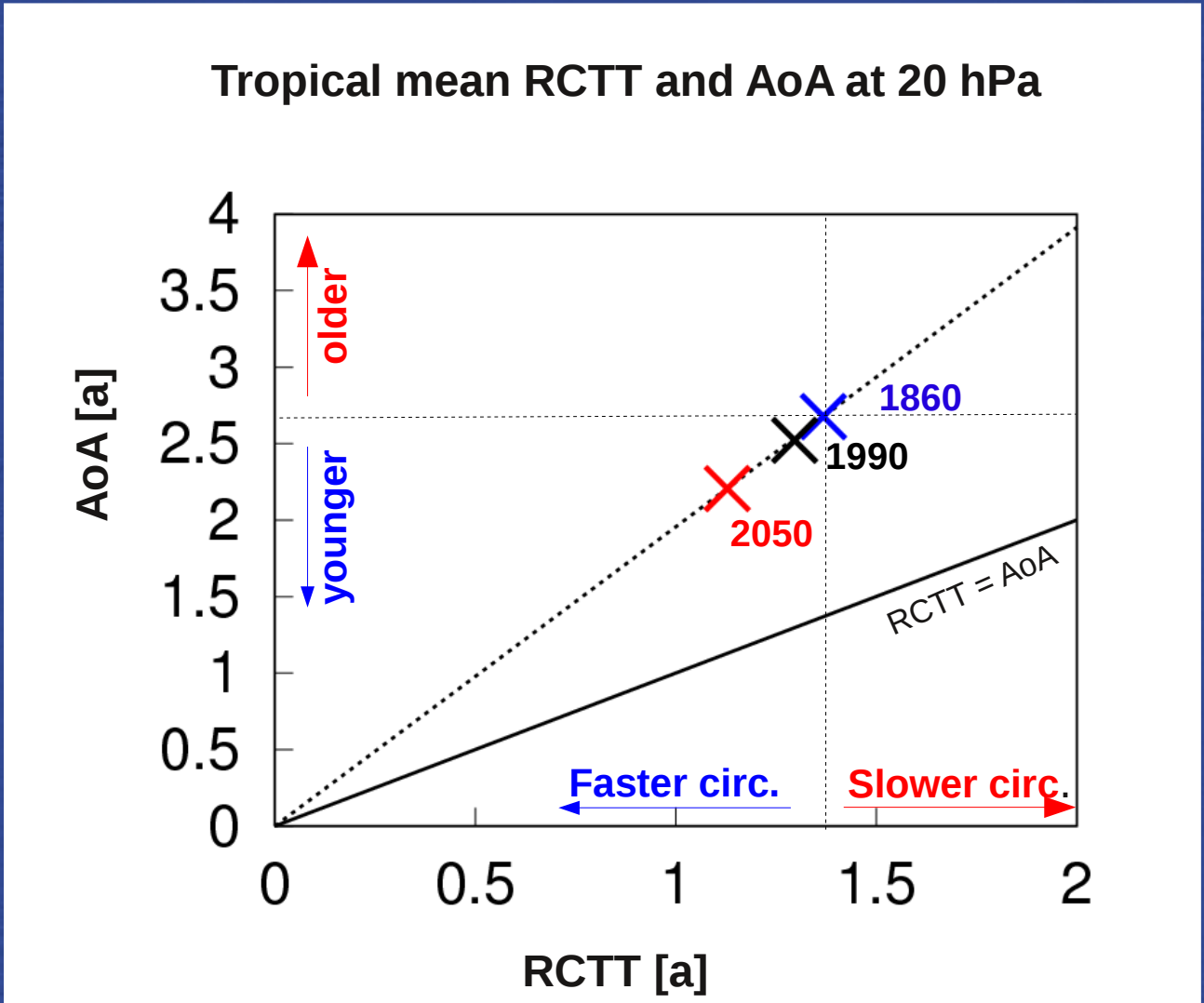
For details, see:
Garny et al., 2014,
Submitted to JGR

Long-term changes in AoA



About half the decrease in AoA is due to a decrease in RCTTs, the other half is due to a decrease in "Aging by mixing".

RCTT - AoA Scatter plots



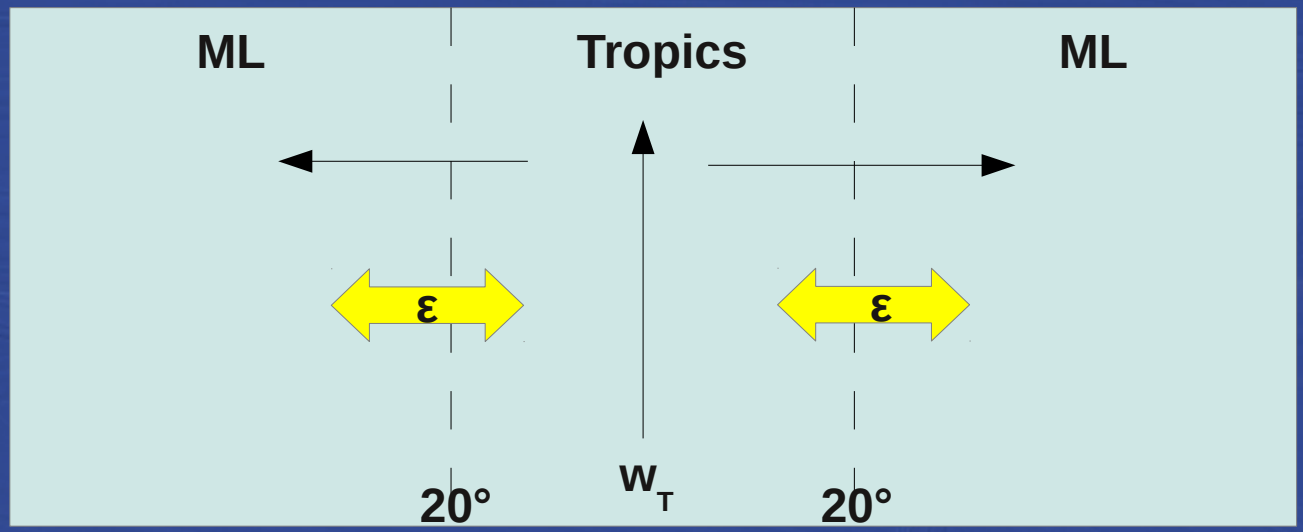
Increase in residual circulation
=> decrease in RCTT

The decrease in AoA is about twice as strong as in RCTT

Decrease in AoA linearly related to decrease in RCTT

Tropical Leaky Pipe Model

Using the TLP Model by Neu&Plumb 1999 to understand the GCM results



Simplest case → analytical solution

2 Free parameters: - tropical upward velocity w_T

- mixing efficiency ε:

ratio of "two-way mixing mass flux" to "net mass flux"

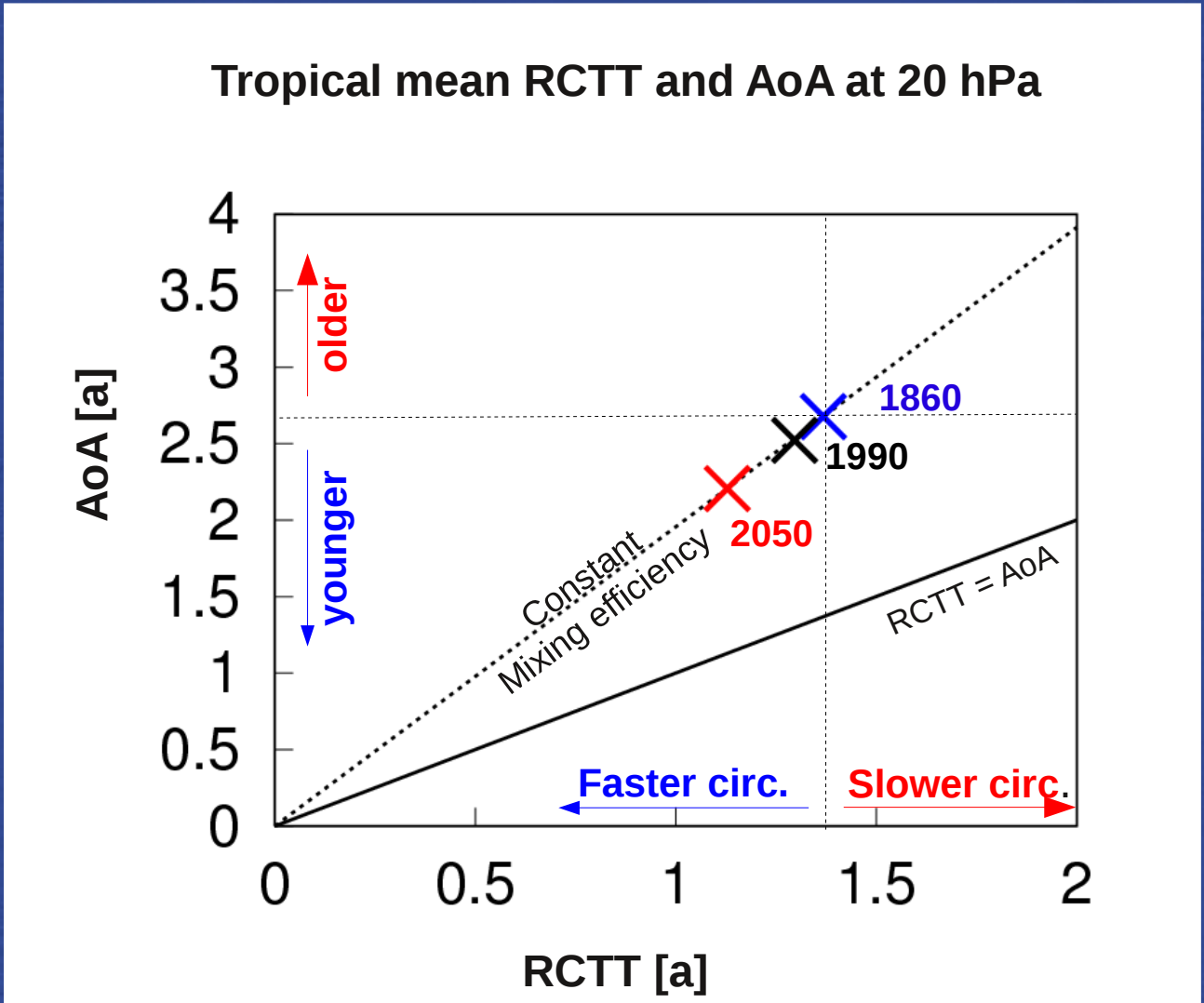
$$AoA(w,\varepsilon) = \frac{1+\varepsilon\left(1+\alpha^{-1}\right)}{w_T}\left(z-z_T\right)$$

$$Aging\,by\,mixing = AoA - RCTT = \frac{\left(1+\alpha^{-1}\right)\varepsilon}{w_T}\left(z-z_T\right)$$

$$AoA/RCTT = \frac{1}{\left(1+\alpha^{-1}\right)\varepsilon}+1$$

α = mass tropics/ mass extratropics

RCTT - AoA Scatter plots



The ratio AoA/RCTT is determined by the "mixing efficiency ε"

The mixing efficiency in 3 GCM equilibrium climate states remains close to constant (ε = 0.32)

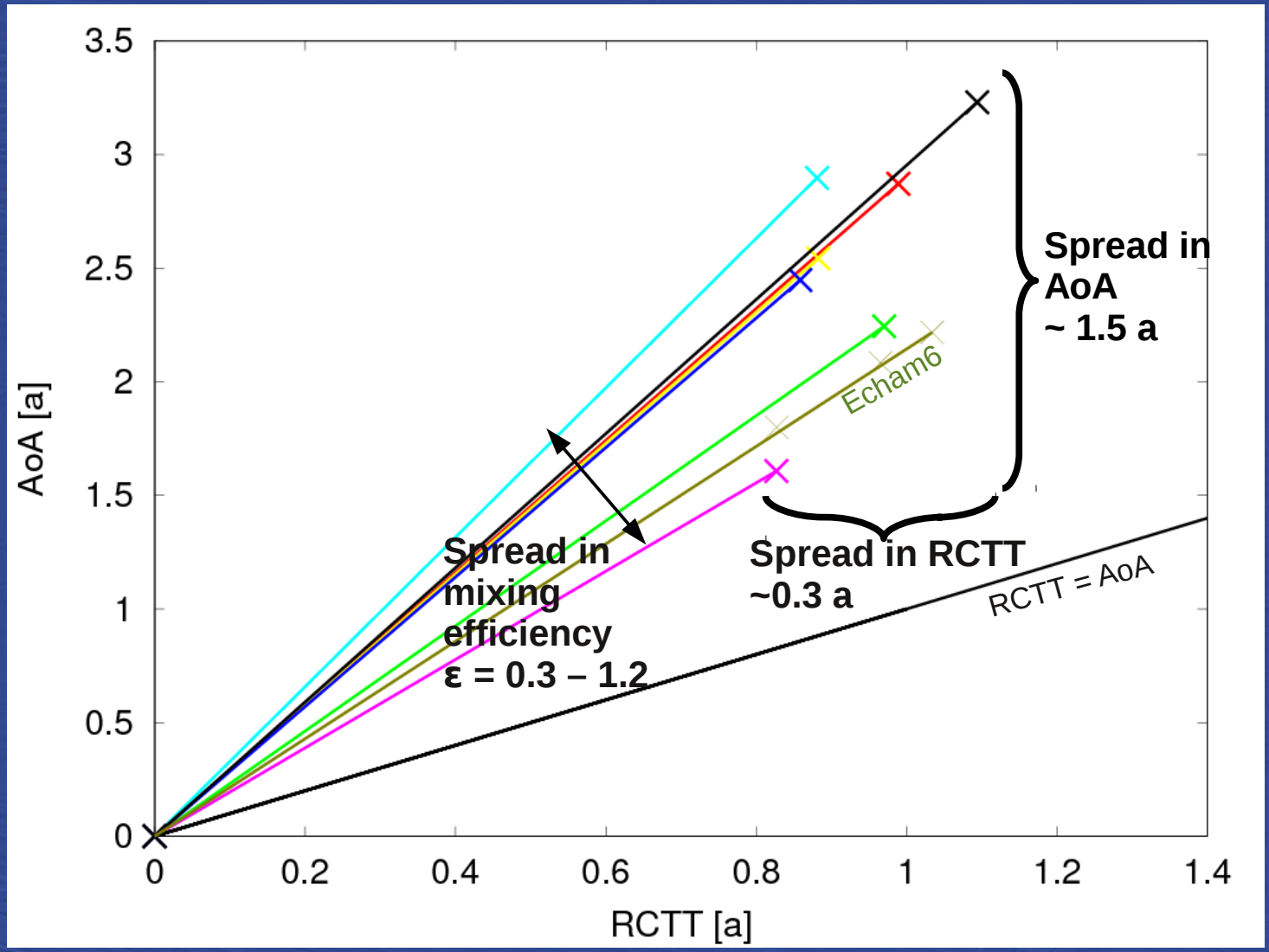
i.e.,
Two-way mass flux across the subtropical barrier increases proportionally to the residual mass flux

"Mixing" generally amplifies changes in AoA due to changes in the residual circulation

For details, see:
Garny et al., 2014,
Submitted to JGR

RCTT - AoA Scatter plots: Model spread (7 CCMVal models)

Spread in simulated tropical AoA and RCTT at 30 hPa (mean 2000-2009)

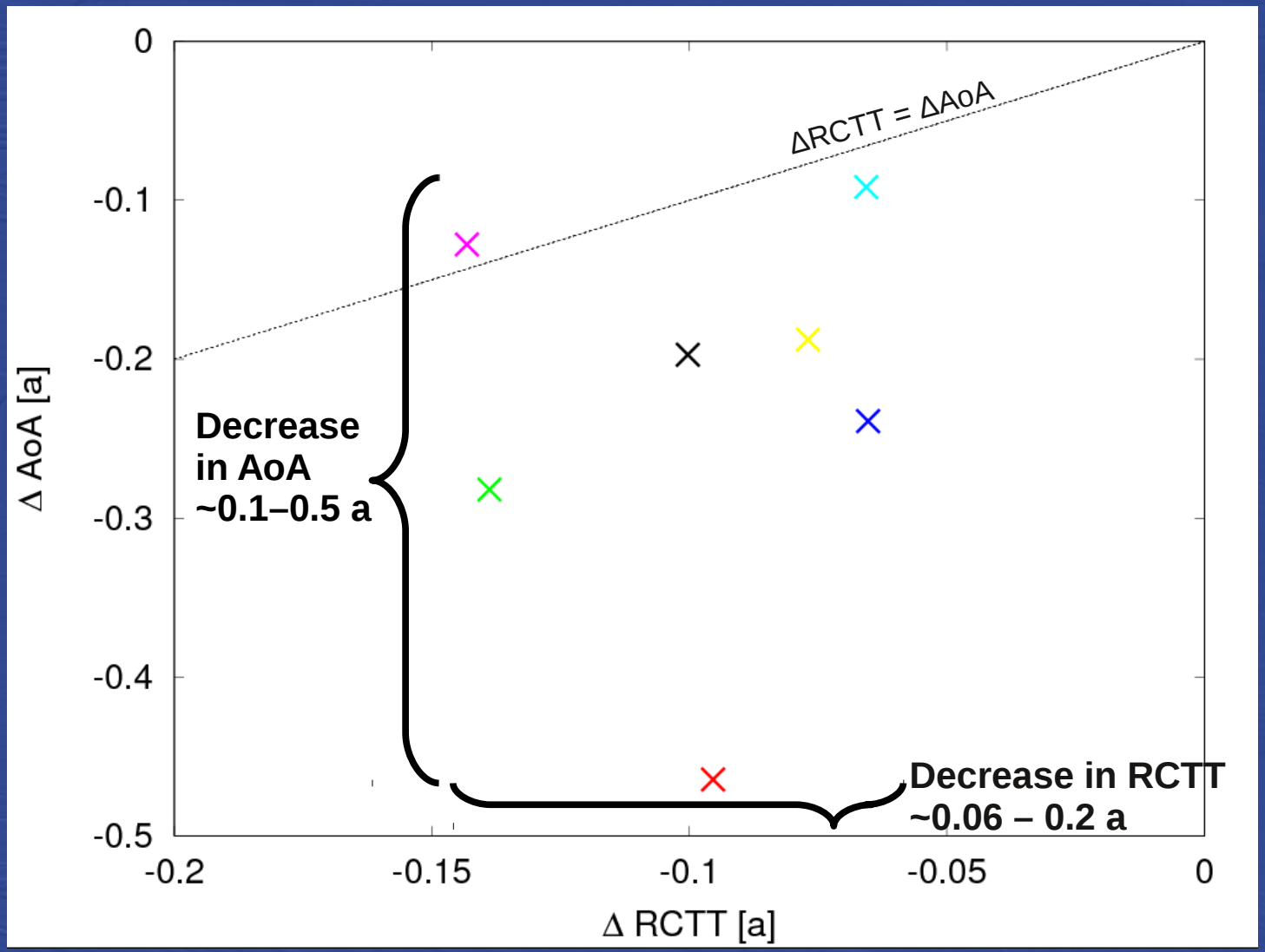


AoA > RCTT for all models (i.e. mixing ages air, as expected)

Simulated AoA differs because:
- the residual circulation strength differs
- the mixing efficiency differs

RCTT - AoA Scatter plots: Model spread (7 CCMVal models)

Spread in simulated tropical AoA and RCTT at 30 hPa (Difference 2040s - 2000s)



-RCTT decreases for all models (due to strengthening of residual circ.)

- AoA decreases more strongly than RCTT for all but one model (i.e. mixing generally amplifies the AoA changes)

- no linear relationship between RCTT changes and AoA changes because mixing efficiency differs between models!

Summary

1. The effects of “mixing” on AoA are quantified as the difference of “residual circulation transit times” to AoA (Aging by mixing)

2. Additional aging by mixing is caused by mixing between tropics and extratropics, that leads to the recirculation of air parcels through the stratosphere.

3. According to 3 equilibrium climate model simulations, the mixing mass flux is strongly linked to the residual mass flux (i.e. constant mixing efficiency)

This implies that under an uniform increase in the residual circulation, mixing amplifies the reduction in AoA.

4. In a set of CCMVal-2 models, simulated AoA and its changes strongly vary. Simulated AoA depends on the mixing efficiency, that strongly varies between models

These variations in the mixing efficiency might be due to different “dynamics” (e.g. wave spectrum) and/or “numerics” (e.g. advection scheme, diffusivity,...)

Most of the results can be found here: Garny et al., 2014, Submitted to JGR
If you are interested & for question email Hella: Hella.Garny@dlr.de