Significant contributions of volcanic aerosols to the decadal changes in the stratospheric circulation

Mohamadou Diallo

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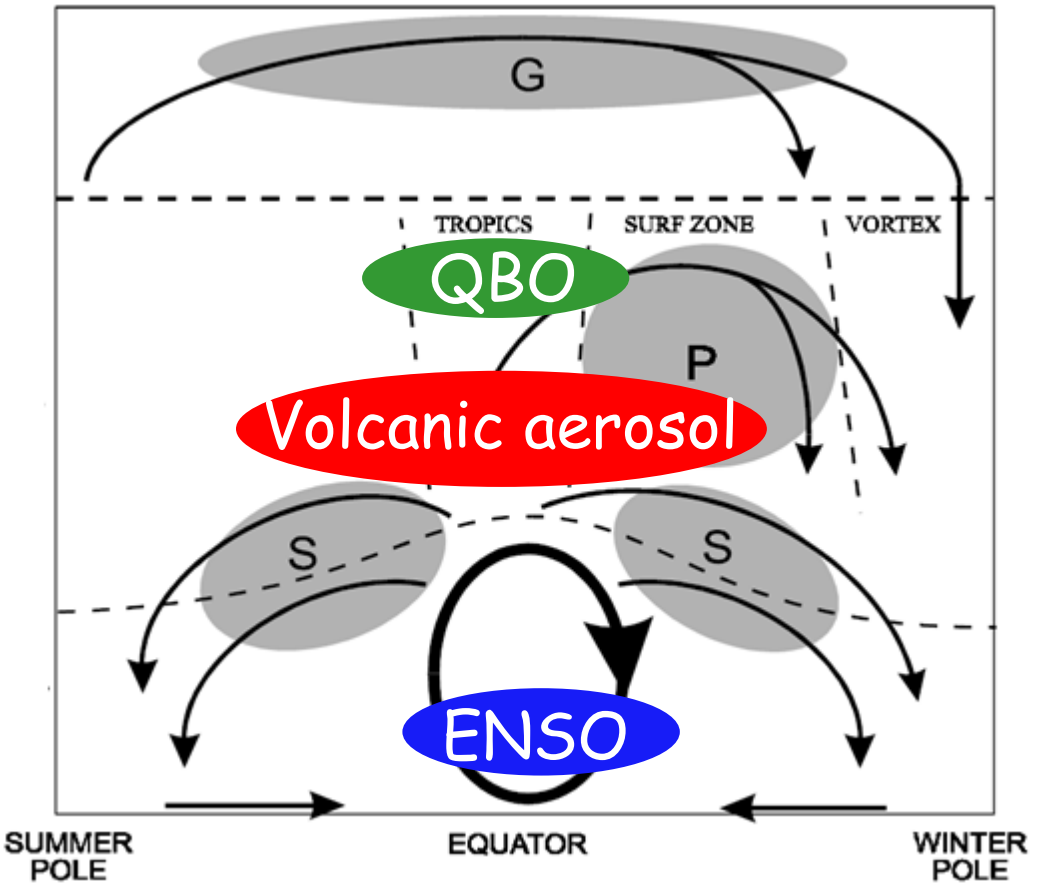
I.- Impact of the natural variability on BDC

❖ BDC is modulated by

- ✓ **QBO phases:** E_{QBO} enhances upward transport, while W_{QBO} reduces and enhances poleward [Plumb & Bell,1982].
- ✓ **ENSO events:** El Nino enhances the tropical upwelling (reversed for La Nina) [Randel et al., 2009].
- ✓ **Volcanic aerosols** modify the circulation via their effects on longwave and shortwave radiation [Robock, 2010].

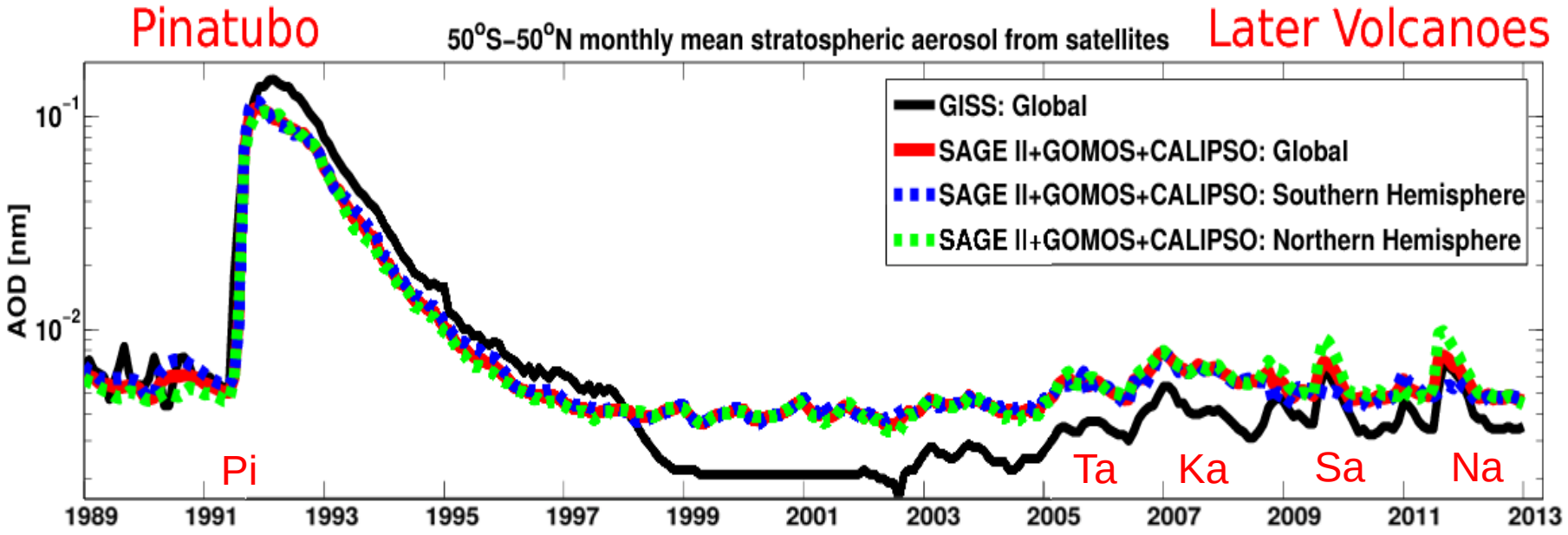
❖ AoA is the residence time of an air parcel in the stratosphere since it crosses the tropopause.

Age of air metric of the BDC



[Plumb, 2002]

I.- Stratospheric volcanic aerosol variations



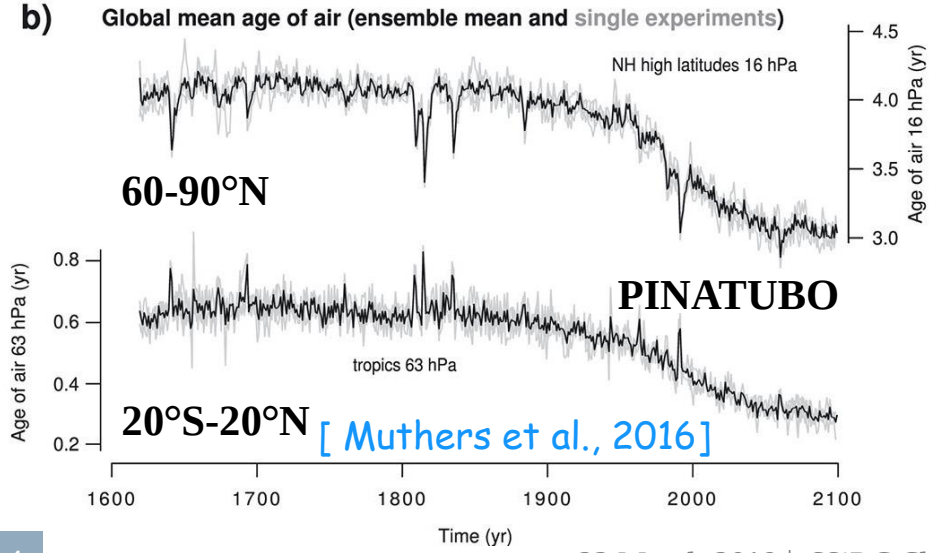
[Sato et al., 1993]
[Vernier et al., 2011]
[Khaykin et al., 2018]

- 1994-1996 : Mt Pinatubo plume decay
- 1996-2002 : Relative clean period
- 2002-2010 : Quasi permanent influence of small volcanic eruptions
  - ✓ Ruang-Raventador (2002), Manam (2005), Soufriere Hills & Tavurvur (2006), Kasatochi (2008), Sarychev & Merapi (2010), Nabro (2011)

I.- Motivations

Climate Models versus Era-Interim

- Common result in models after large volcanic eruptions is :
  - ✓ Decreasing AoA in the mid and upper stratosphere [Garcia et al., 2011; Pitari et al., 2016; Muthers et al., 2016; Garfinkel et al., 2017].
  - ✓ Good agreement in increasing tropical upwelling.



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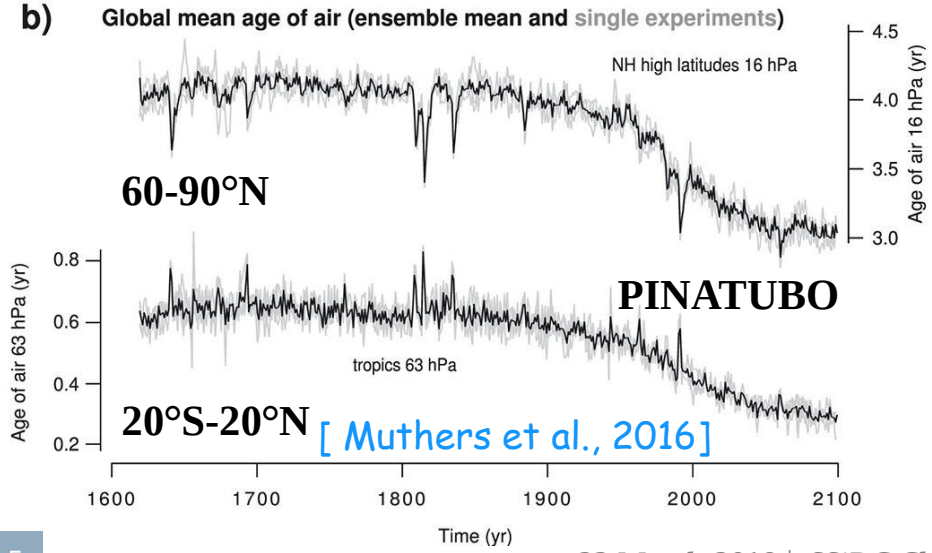

- ERA-Interim shows increasing AoA anomalies related to the Pinatubo and later volcanic eruptions in the lower stratosphere [Diallo et al., 2012].

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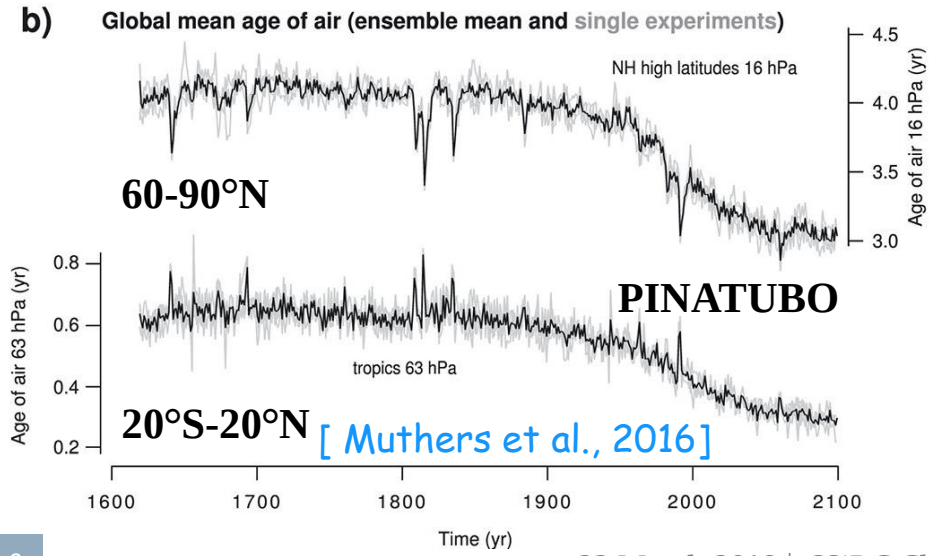

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I.- Open questions :

Improving our understanding on the BDC response to the volcanic eruptions in the reanalyses is crusial. We look at:

- ✓ How does the AoA response to volcanic aerosols in the reanalyses?
- ✓ What is the possible cause of the model-observation discrepancy?

II.- Method: Multiple regression

- The timeseries of monthly zonal mean AoA from CLaMS simulations, driven by ERA-I and JRA-55 reanalyses, have been decomposed in term of :
  - ✓ Linear Trend
  - ✓ Quasi-Biennial Oscillation (QBO) with delay
  - ✓ El Nino Southern Oscillation (ENSO) with delay
  - ✓ Stratospheric Aerosol Optical Depth (AOD) with delay
  - ✓ Annual Cycle
  - ✓ Residual (solar variations not considered)

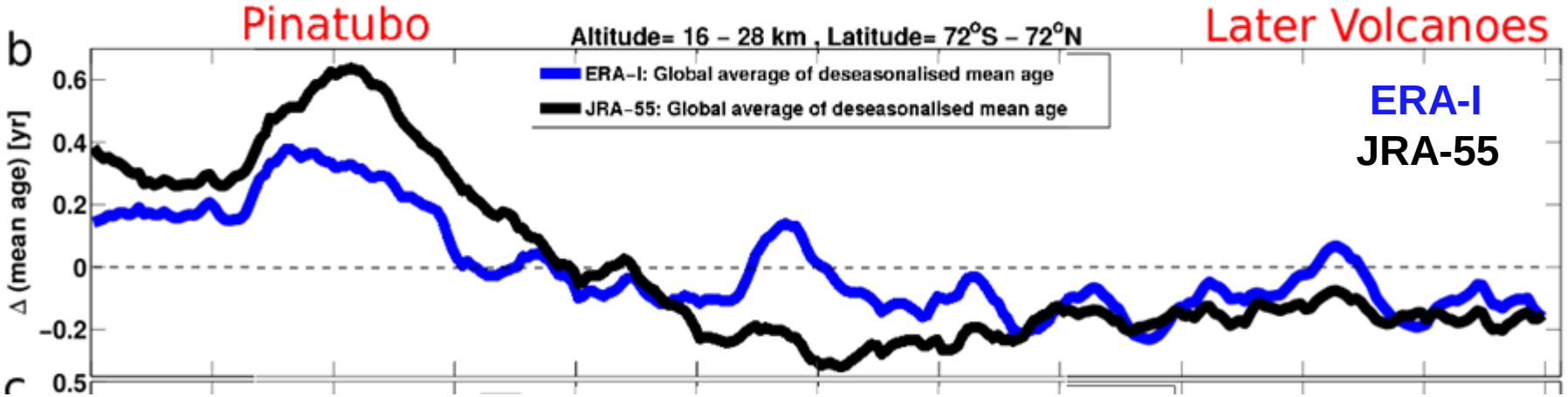
- The model yields [Diallo et al., 2012 ACP; Diallo et al., submitted in ACP]:

$$\chi(t,\phi,z) = a(\phi,z)\cdot t + C(t,\phi,z) + \sum_{k=1}^{3} b_k(\phi,z)\cdot \mathrm{P}_k(t-\tau_k(\phi,z)) + \varepsilon(t,\phi,z)$$

- Coefficients (a, b_k, τ_k & C) are calculated by minimising the residual ε.

- Proxies (P_k) of QBO, ENSO and AOD used are:
  - ✓ Normalized QBO index from CDAS/Reanalysis zonally averaged winds at 30 hPa
  - ✓ Normalized Mulvariation ENSO index (MEI) [Wolter et al., 2011].
  - ✓ AOD from satellites merged data sets [Vernier et al., 2011].

III.- Volcanic aerosol effect on CLaMS AoA



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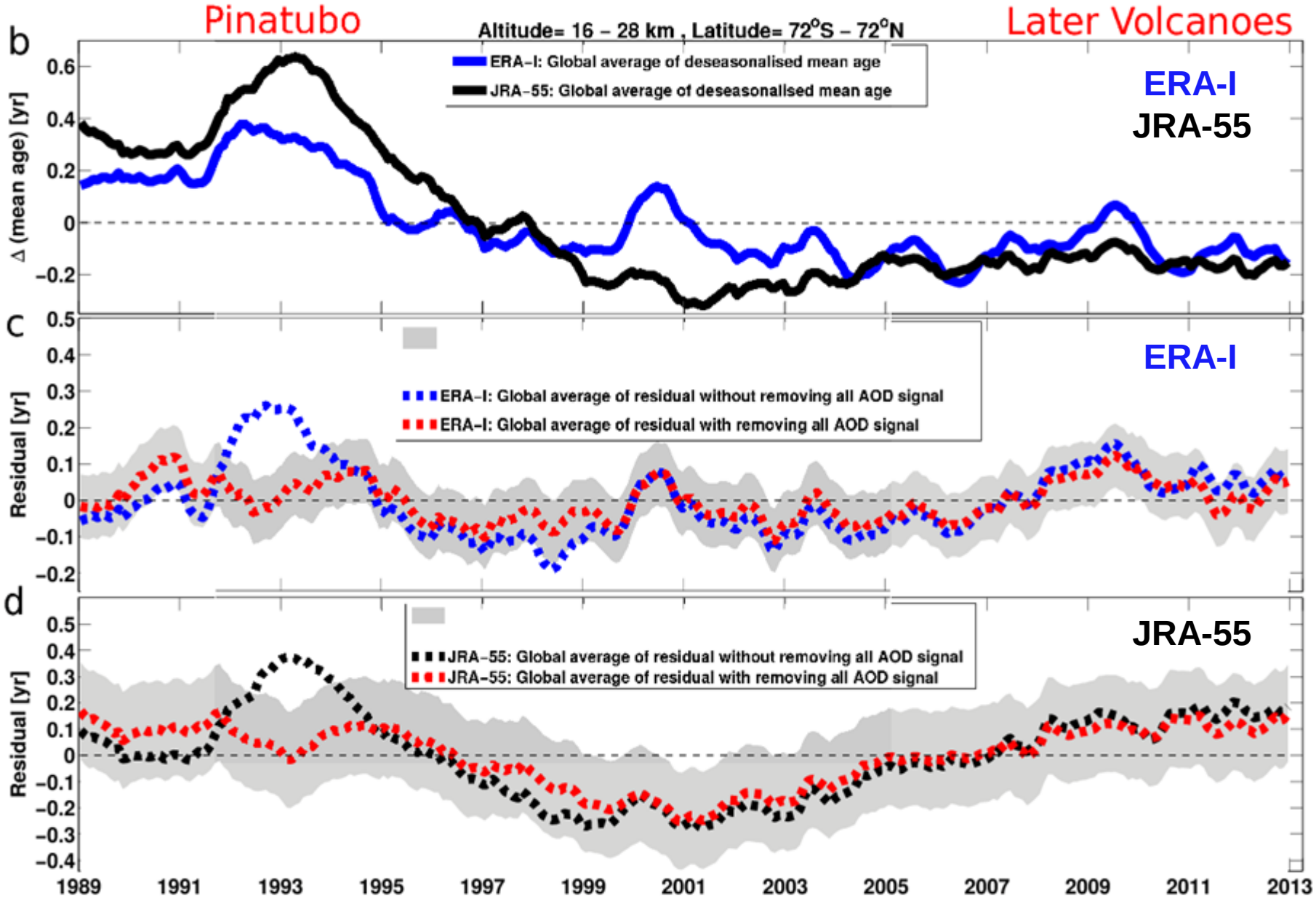
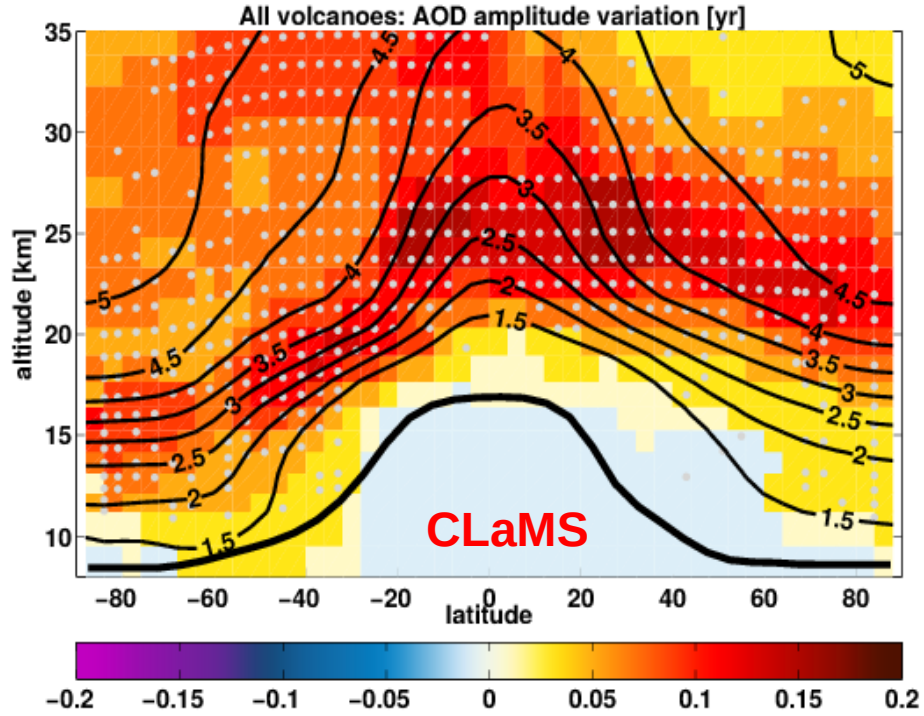


III.- Volcanic aerosol effect on AoA (Pinatubo)

a



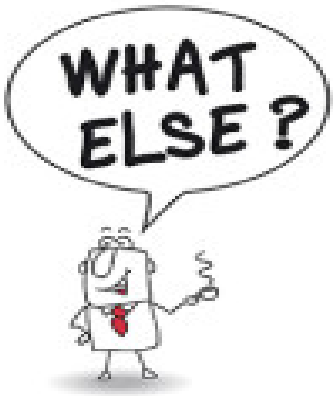
Why do reanalyses show increasing AoA?

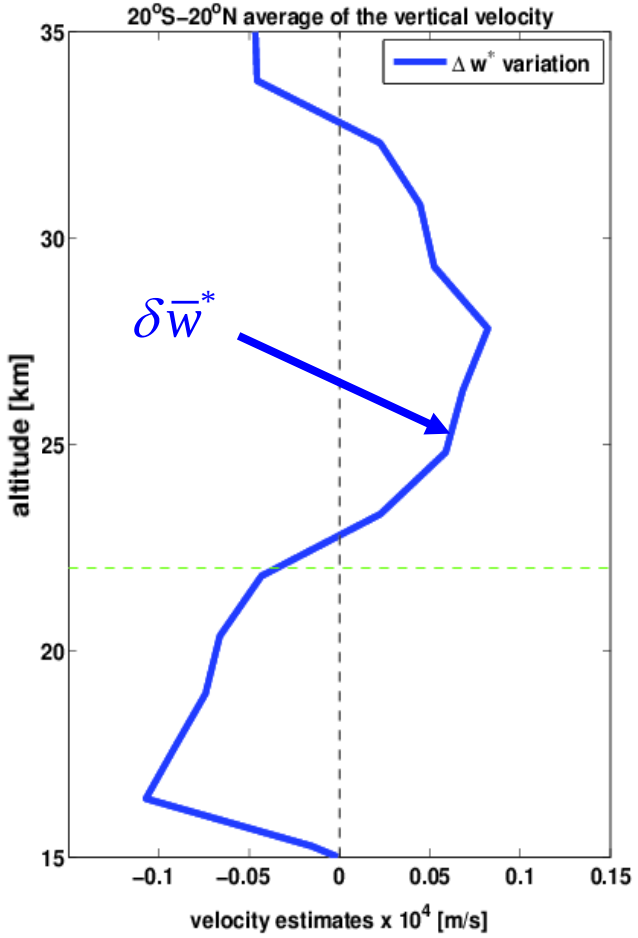
- Pinatubo eruption significantly impacts the BDC by increasing the AoA by up to 0.25 yr in the lower stratosphere.
- The latitudinal dependency of the pattern of changes results from the dispersion of the plume due to different QBO phases.

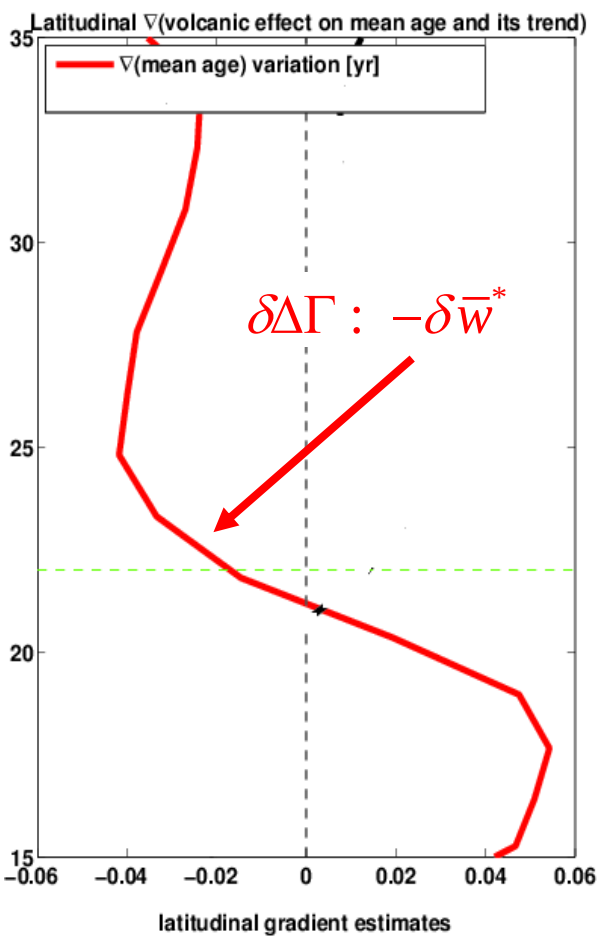
IV.- Mechanisms: Tropical upwelling

- Extratropics-tropics AoA difference (Latitudinal gradient method) is directly related to the tropical upwelling velocity, $\Delta\Gamma \sim 1/w^*$, and independent of the mixing strength [Neu and Plumb, 1999].
- Increasing tropical upwelling at the upper levels and decreasing upwelling at the lower levels related to volcanic aerosols are consistent with models.

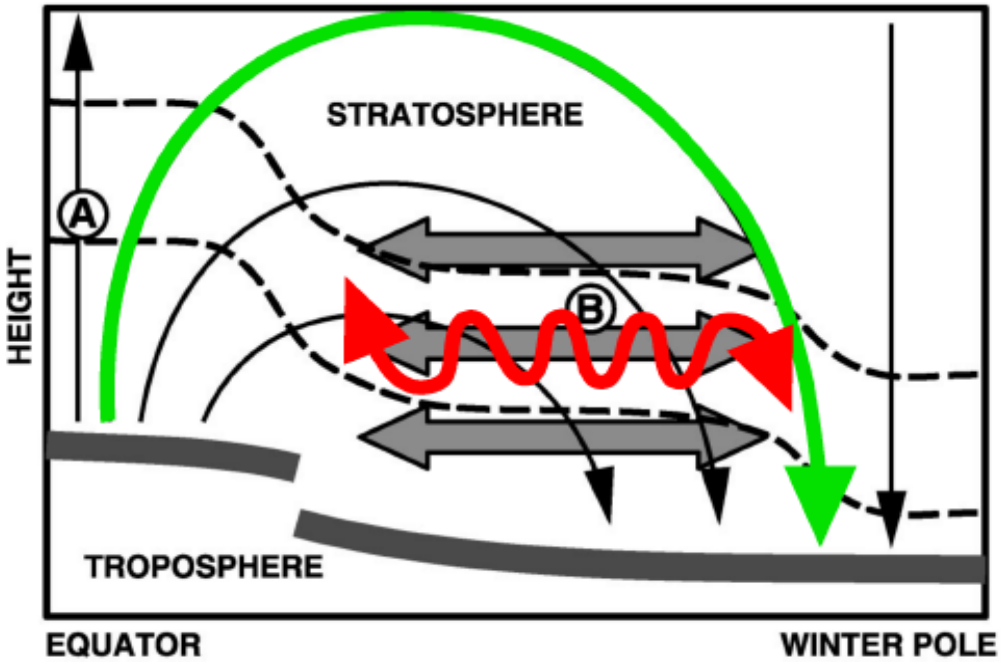
Humm!
Increasing Upwelling,
Not ENOUGH?







IV.- AoA decomposition into RCTT and Mixing



★ integrate continuity eqn. along residual circulation:

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

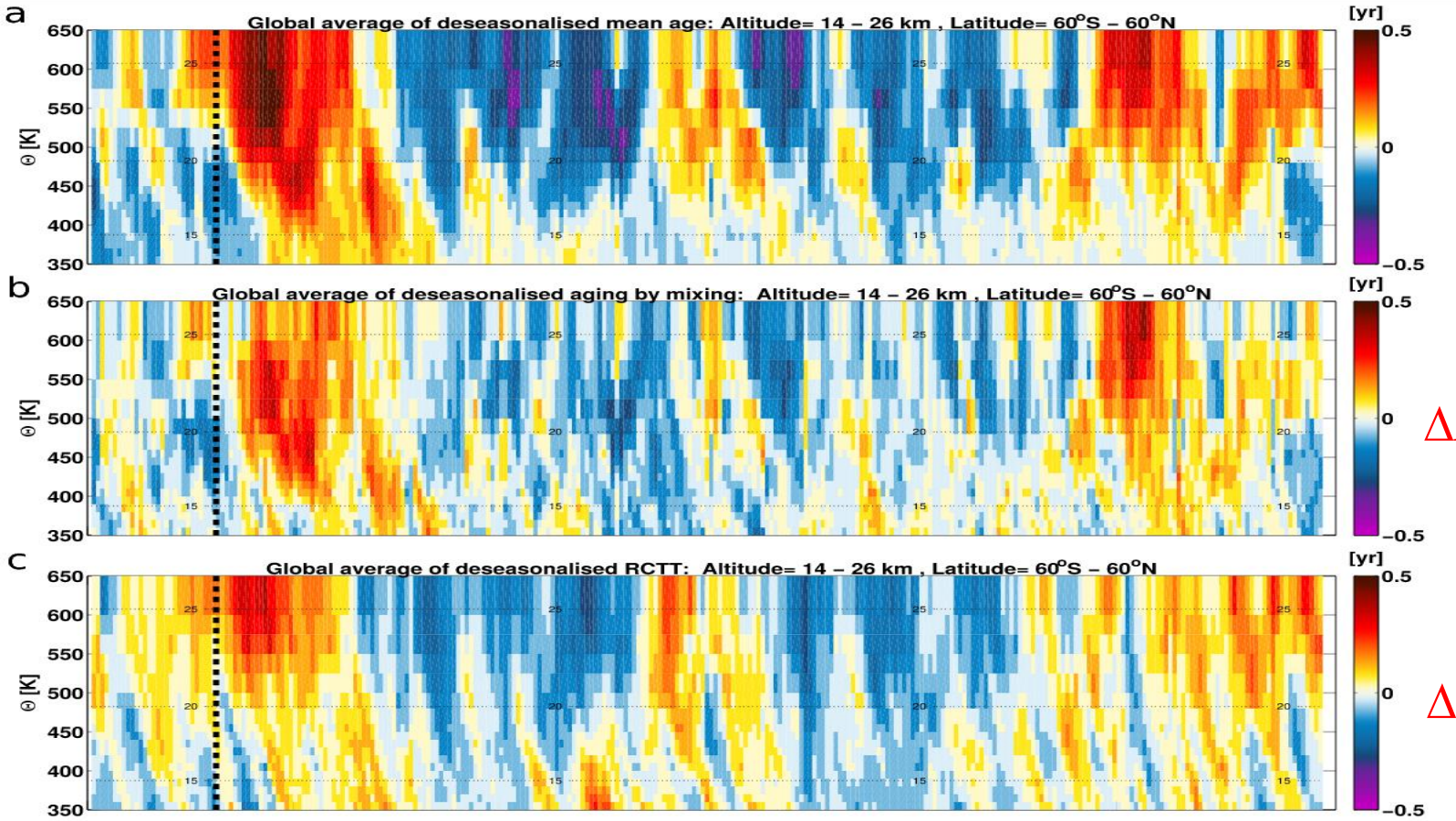
resid. circulation — eddy mixing

$$\overline{\Gamma} = \tau_{\mathrm{RCTT}}(\boldsymbol{x}, t) + \int_{t_0}^{t} \mathscr{M}(\boldsymbol{x}, t)\, \mathrm{d}t'$$

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

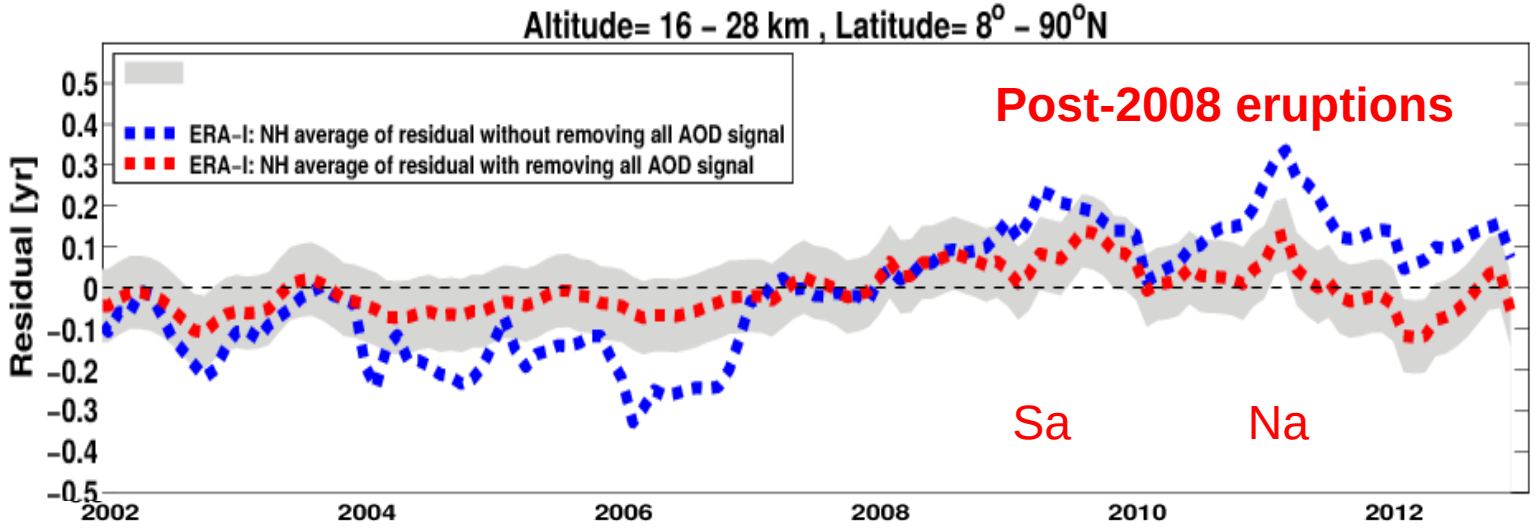
[Ploeger et al., 2015 GRL]

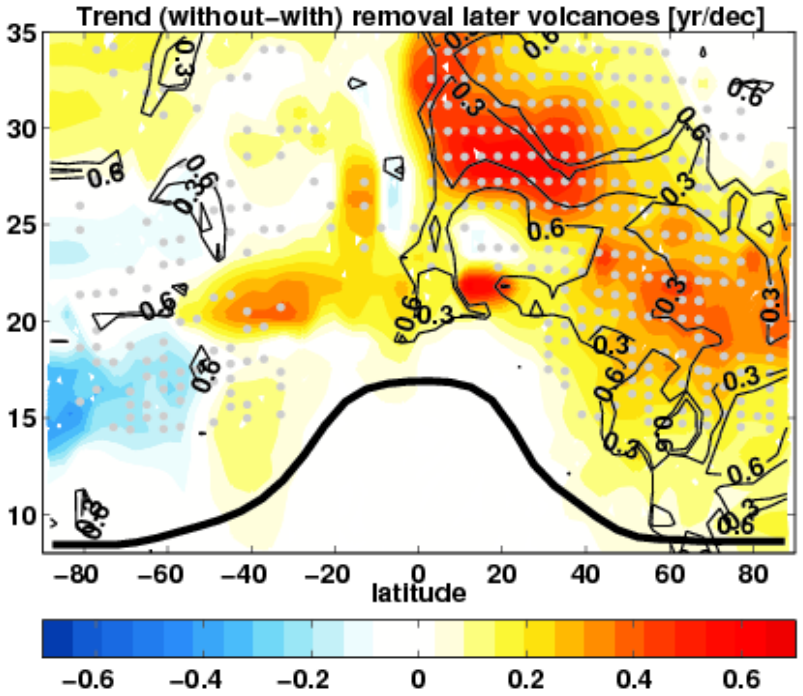
IV.- Mechanisms: Aging by mixing and RCTT



Increase of tropical upwelling due to volcanic aerosol implies that the global increase of AoA is mainly attributed to increasing aging by mixing and RCTT above 22km.

V.- Volcanic aerosol effect on 2002-12 AoA trend

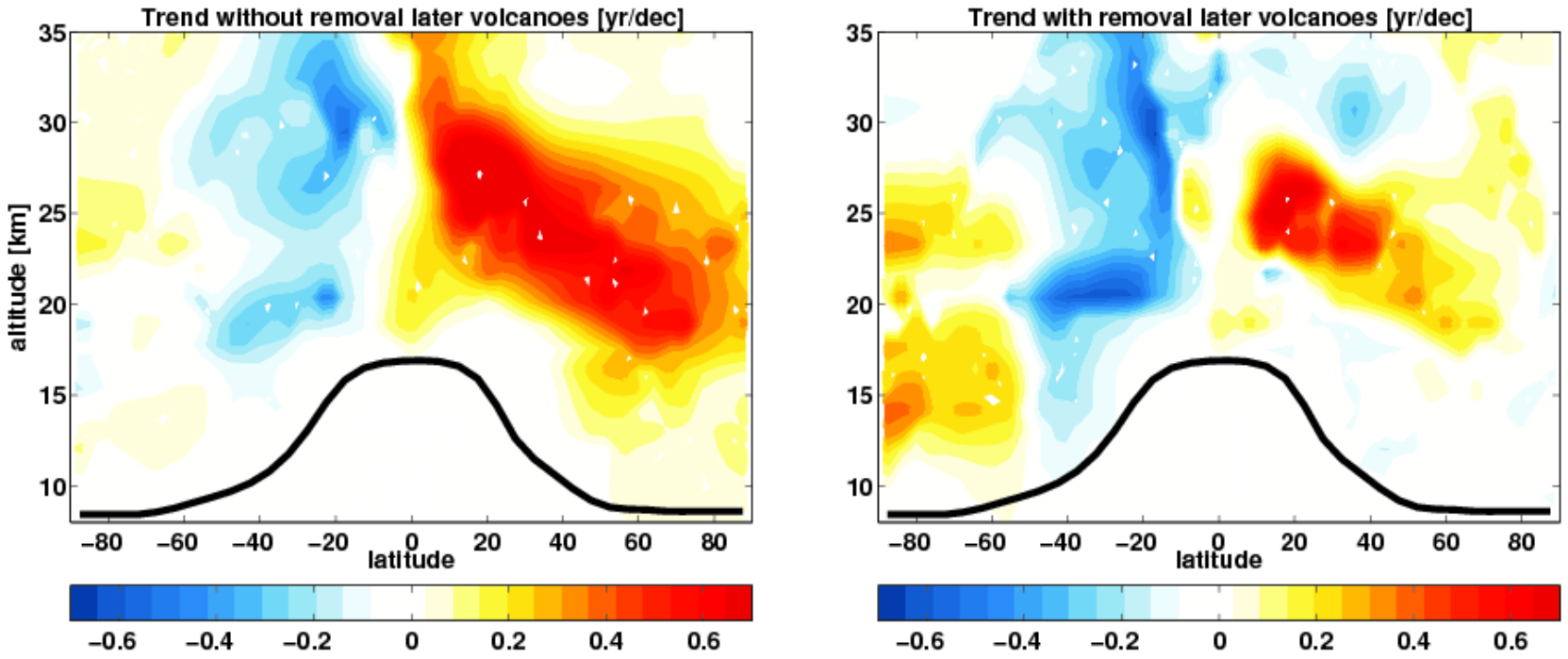




- Later minor eruptions after 2008 significantly increase AoA.
- The post-2008 eruptions significantly change the decadal trend in AoA for the 2002–2012 period.
- Shift of the global circulation pattern toward 5S also matter [Stiller et al., 2017].

V.- Volcanic aerosol effect on tracers' asymmetry

Post-2008 eruptions



Same dipole is observed in trace gases such as O3, N2O, N2O and HCl [Ploeger et al., 2014; Mahieu et al., 2014; Nedoluha et al., 2015; Yela et al., 2017].

Take home message

- ✓ We found a significant contributions of volcanic aerosols to decadal pattern of changes in the BDC:
  - ❖ Mainly dominated by **Pinatubo** eruption over 1989-2012.
  - ❖ **Pinatubo** explains more than 35% of the decadal trend.
  - ❖ **Later volcanoes** explain 50% of the 2002-2012 decadal trend.
- ✓ Main difference between the reanalysis and the models' response concerns the depth/strength of the deep versus shallow branch changes.
  - ❖ **In the reanalysis**, the increasing AoA is stronger and reaches high into the stratosphere,
  - ❖ **In the models**, it is confined to the lower stratosphere.
- ✓ Increase of tropical upwelling due to volcanic aerosol implies that the global increase of AoA is related to mixing effects at all level and RCTT above 22km.

Diallo et al., GRL 2017

Thank you for listening!

Any questions