Impact of the QBO phases on transport of sulfate aerosols in the stratosphere

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MOTIVATION

The lifetime of stratospheric sulfate aerosols and their transport depends on aerosol microphysical processes, the related particle size, sedimentation and transport. These parameters differ clearly between models causing, e.g. a wide range of radiative forcing of stratospheric aerosols after stratospheric sulfur injections (Niemeier and Tilmes, 2017). Marshall et al (2017) show up to 10 months difference between the time of occurrence of the global maximum sulfate burden after a simulated Tambora-like eruption in an inter-comparison of four aerosol climate models (Fig. 1). Beside aerosol microphysics, stratospheric dynamics, e.g. the representation of the quasi biennial circulation (QBO), are not the same in these models.

Transport processes in the stratosphere depend on the QBO phase. A westerly phase in the lower stratosphere increases tropical confinement of the aerosols and reduced meridional transport (Fig.2, Niemeier and Schmidt, 2017).
Under high SO_2 conditions OH is limited, which slows down the oxidation of SO_2 and increases the lifetime of SO_2. Within MAECHAM we test a parameterization of this process.

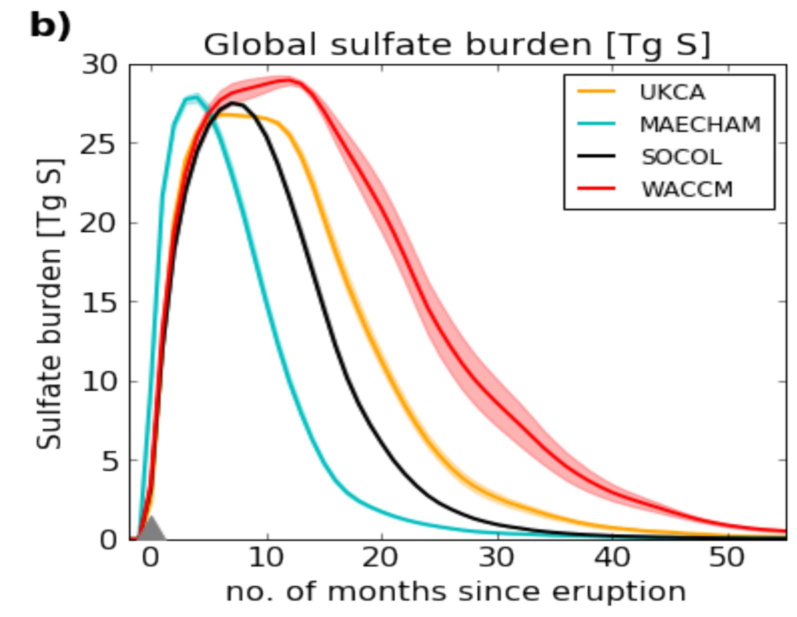
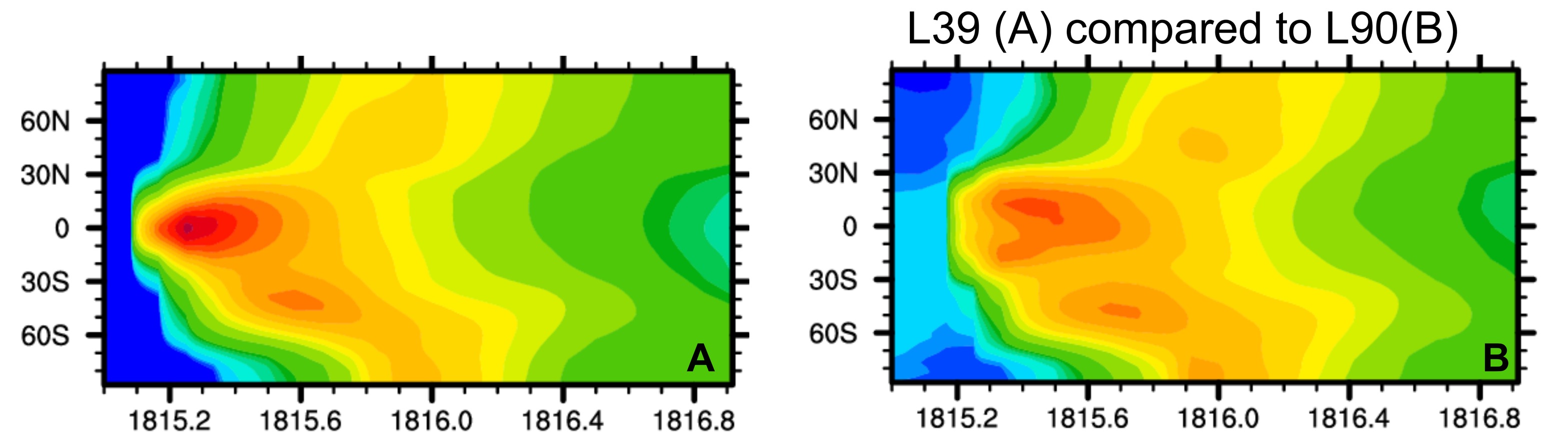


Fig. 1: Global sulfate burden after a Tambora eruption simulated by four different models (from Marshall et al (2018).

Role of QBO for sulfate transport (Tambora)

- Our question was: Does the MAECHAM result depends on the model setup, e.g. number of vertical levels, QBO phase, OH chemistry?
- MAECHAM does not generate a QBO in the 39 levels (L39) version. Increasing the vertical resolution (L90), which generates a QBO, allows us to determine the impact of the vertical model resolution on the lifetime of sulfate in MAECHAM (Fig 3). The maximum burden is delayed by two month, plus one further month when limiting the OH concentration for high SO2 load (Fig. 2 and Fig. 4).
- The impact of the QBO is given in lon/lat plots (Fig. 3) and a vertical cross section (Fig. 4). With westerly winds in the injection height the tropical confinement of the aerosol is stronger and the sulfate concentration twice as high as in an easterly case.

L39 (A) compared to L90(B)



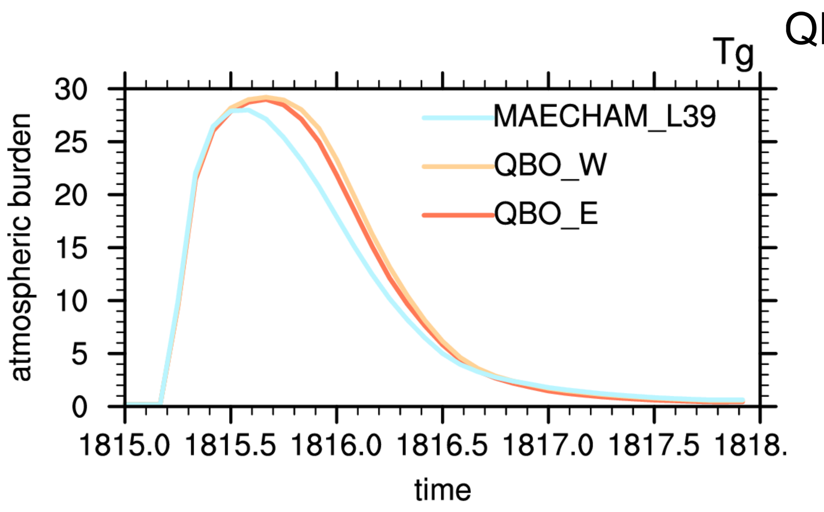


Fig 2: Global sulfate burden of three MAECHAM simulations with different vertical resolutions and different QBO phases.

QBO east phase (B) and west phase (C)

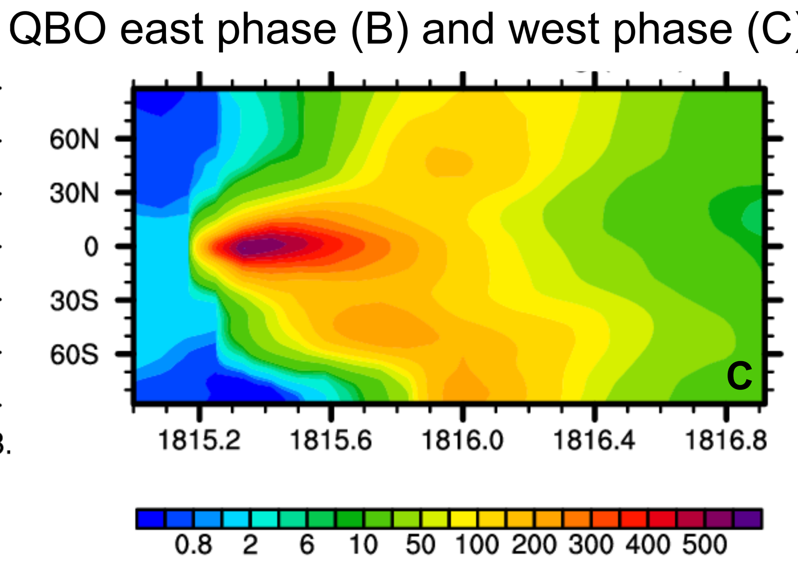


Fig 3: Sulfate burden [kg (SO4) km^{-2}] for three simulations after Marshall et al (2018) with MAECHAM: 39 vertical levels (L39) (A), 90 vertical levels (L90) with sulfur injected into the QBO east phase (B), and L90 with sulfur injected into the QBO west phase (C).

U [m/s], inject into QBO east phase

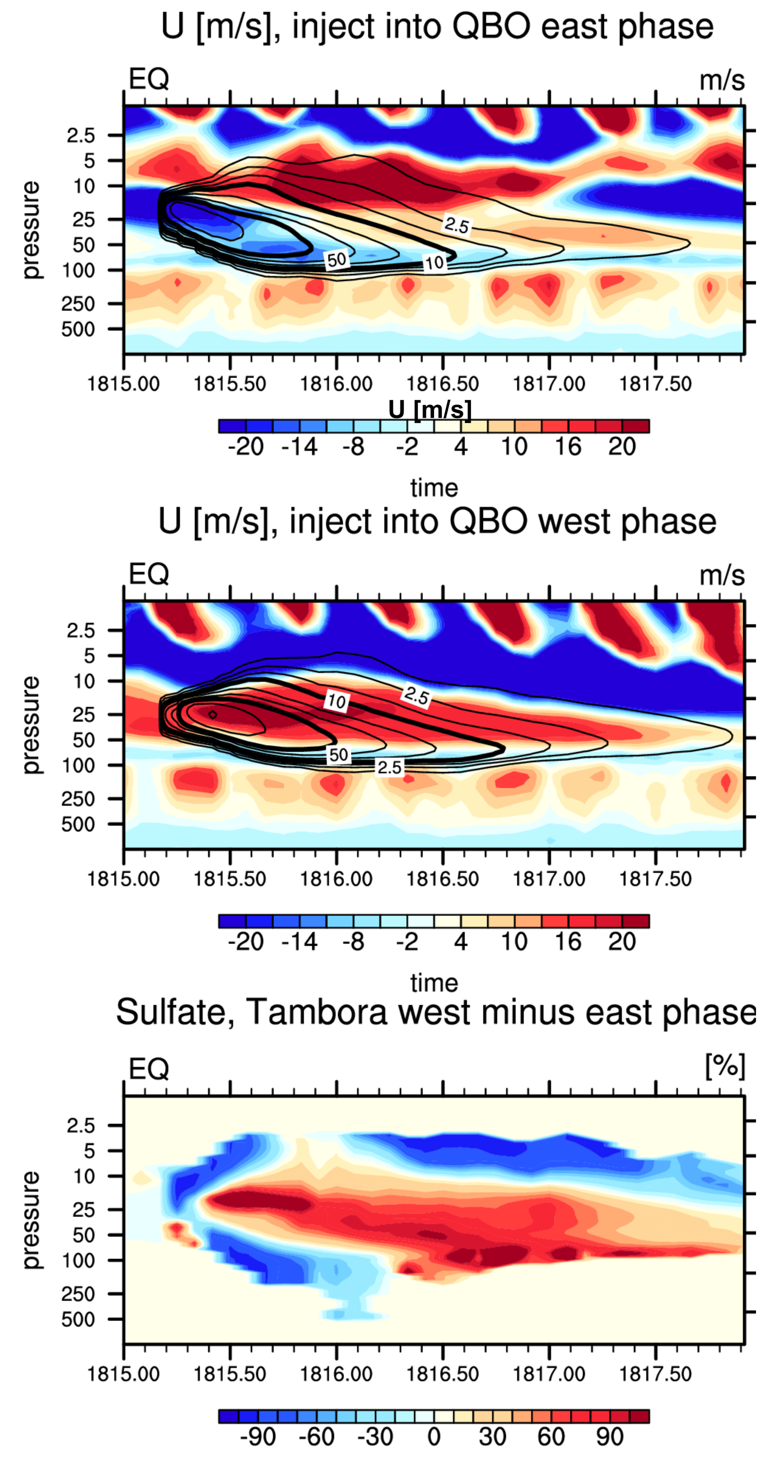


Fig 4: Vertical cross section of zonal wind and sulfate concentration at the Equator for easterly (top) and westerly QBO phase. During westerly phase the sulfate concentration is partly two times larger.

SUMMARY

- The phase of the QBO has impact on sulfate transport and concentration. Tropical westerly jets enhance stratospheric confinement and increase concentration in the tropics.
- MAECHAM shows shorter lifetime compared to SOCOL and WACCM. Lifetime increases with L90 version but is still too short.
- With OH limitation the maximum global sulfate burden gets close to the SOCOL result. But the decline is still faster.
- MAECHAM calculates too high precipitation at the poles. The consequence is strong de-position at the poles. This plays an important role in lifetime of the aerosols, e.g. burden after Tambora eruption decreases when reaching the pole in MAECHAM but far less in WACCM (Fig. 6).
- Transport into extra tropics depends on sulfur evolution and timing of the maximum concentration in a Pinatubo like simulation. Earlier sulfate maximum (no OH limitation) results in transport into southern hemisphere (Fig.7).

Role of sulfur evolution (Tambora and Pinatubo eruption)

OH Limitation

Under very high SO_2 conditions in the stratosphere OH is limited (S.Bekki, pers. com.):

- reaction $OH+O_3$ becomes smaller than SO_2+OH
- SO_2 dominates the conversion of OH into HO_2
- Lifetime of SO_2 increases, later maximum sulfate concentration

When $SO_2 > k\_2 * O_3/k\_3$ OH limits to

$$x = \frac{OHc*(k1+k2)*O_3}{(k1+k2)O_3+k3*SO_2)}$$

k = reaction rates;
OHc = climat. OH concentration
k1 = k(HO_2+OH), k2=k(O_3+OH),
k3 = k(SO_2+OH)

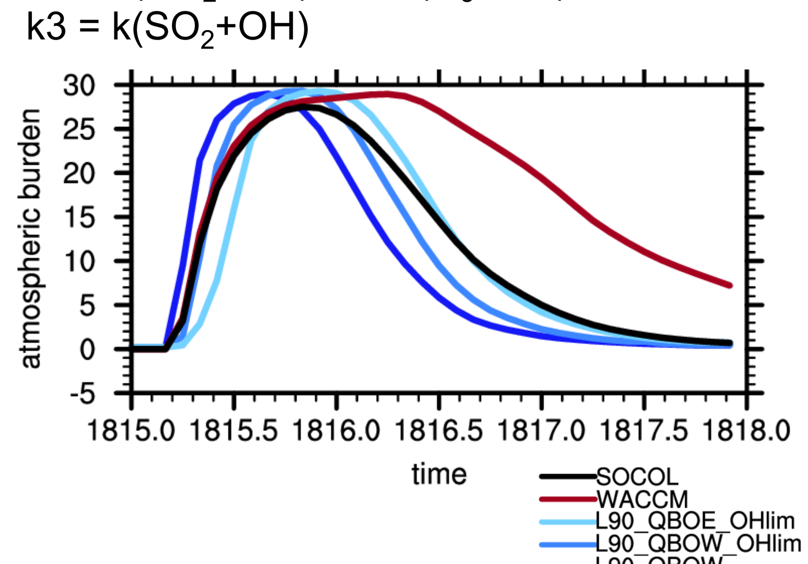


Fig 5: Global sulfate burden (Tg) after Marshall et al (2018).

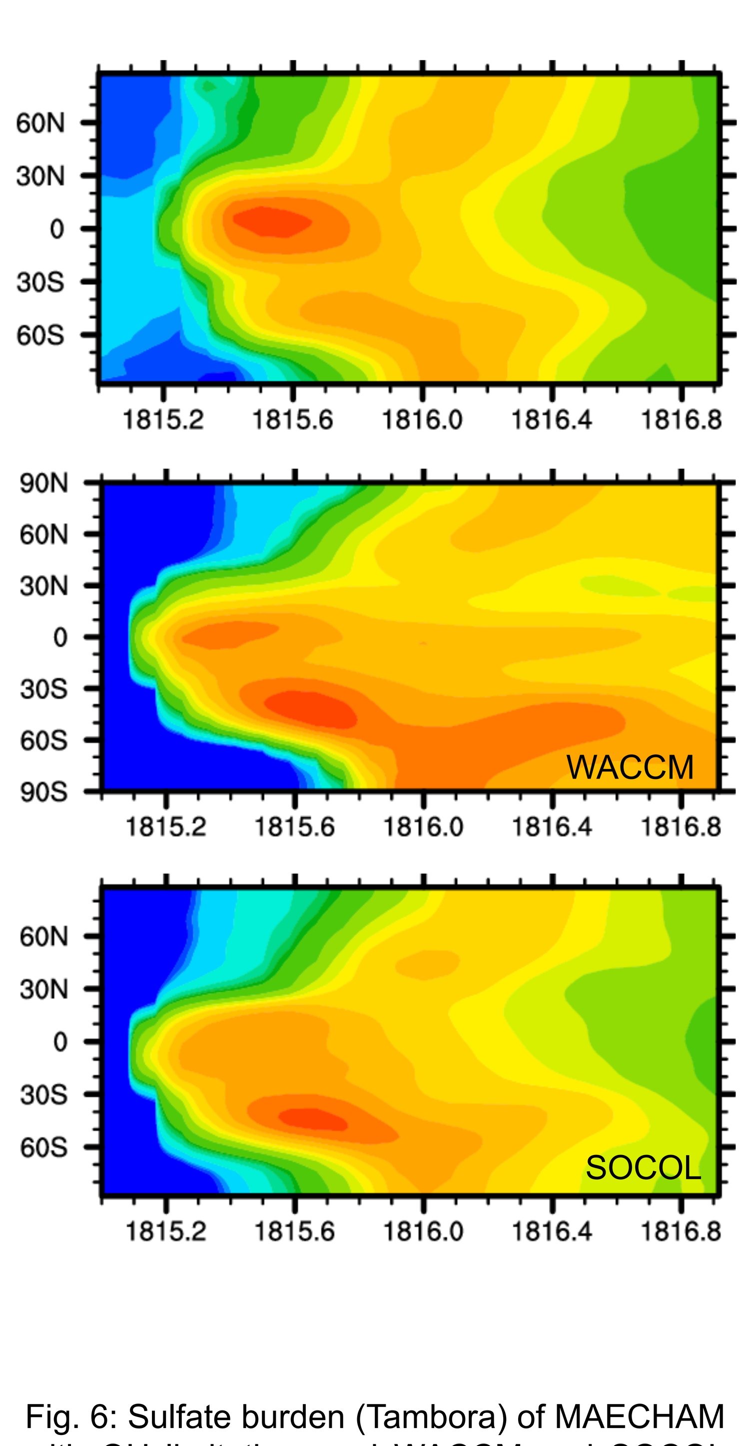


Fig. 6: Sulfate burden (Tambora) of MAECHAM with OH limitation, and WACCM and SOCOL results, both with interactive chemistry.

With OH limitation & nudged QBO

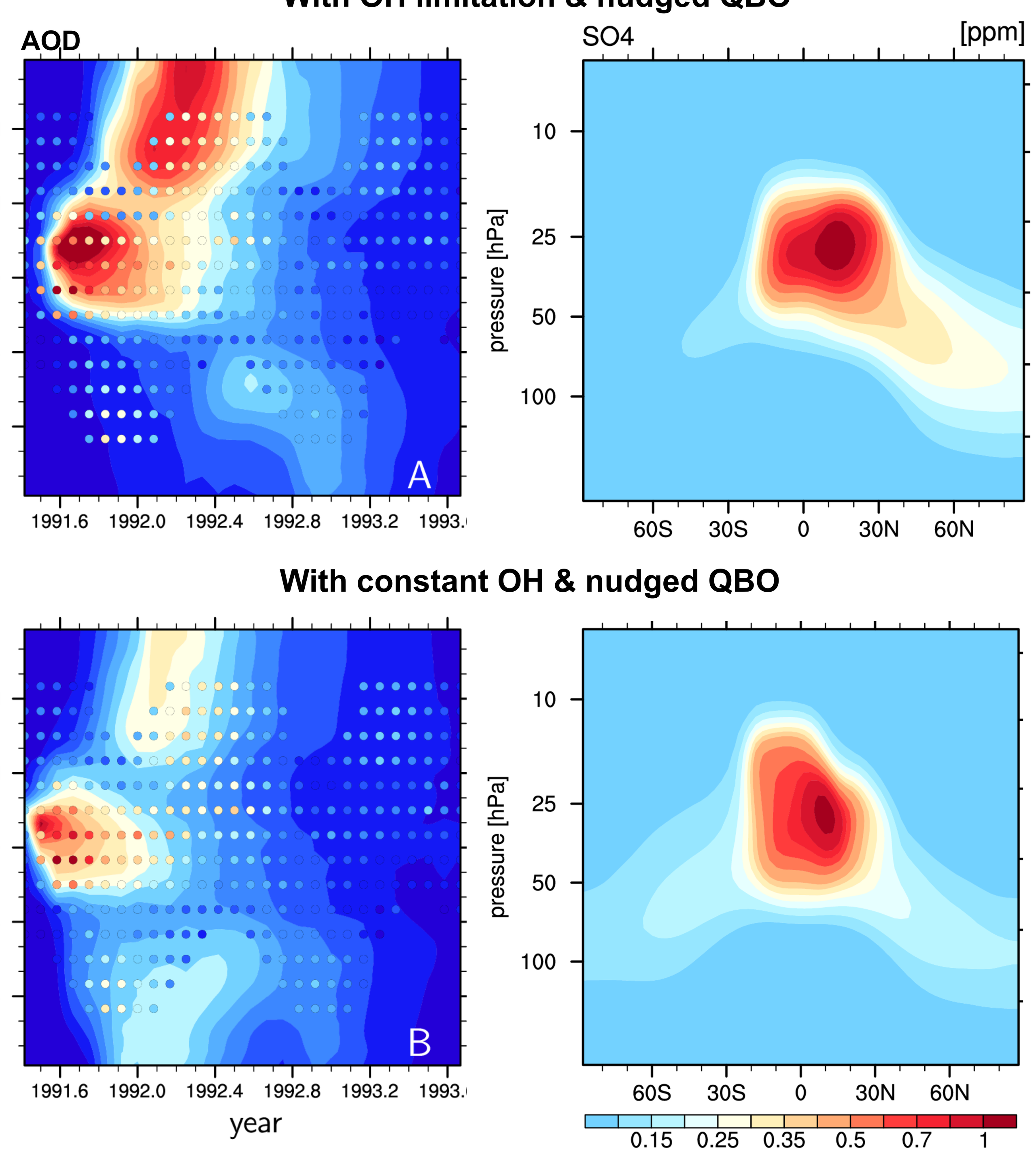


Fig 7: Aerosol optical depth of different Pinatubo like simulations (shaded) and AVHRR observations (circle): with limitation of OH concentration (A) and constant OH concentration (B). The QBO was nudged. with a phase similar to the phase during the 1991 Mt. Pinatubo eruption. Injection rate was 17 Tg SO_2
The transport of the aerosols after the eruption depends strongly on the timing of the sulfur evolution. With OH limitation and, thus, slower SO2 oxidation and later formation of sulfate, transport goes mostly towards the northern hemisphere. With constant OH the sulfate forms earlier and the aerosol still gets into the southward branch of the Brewer-Dobson circulation. The very early southward transport to 15° S is not captured by the model.

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Marshall et al. 2018
Niemeier and Schmidt (2017)
Niemeier and Tilmes 2017

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