Model simulation of the Pinatubo volcanic eruption: direct and indirect effects on stratospheric chemistry and dynamics

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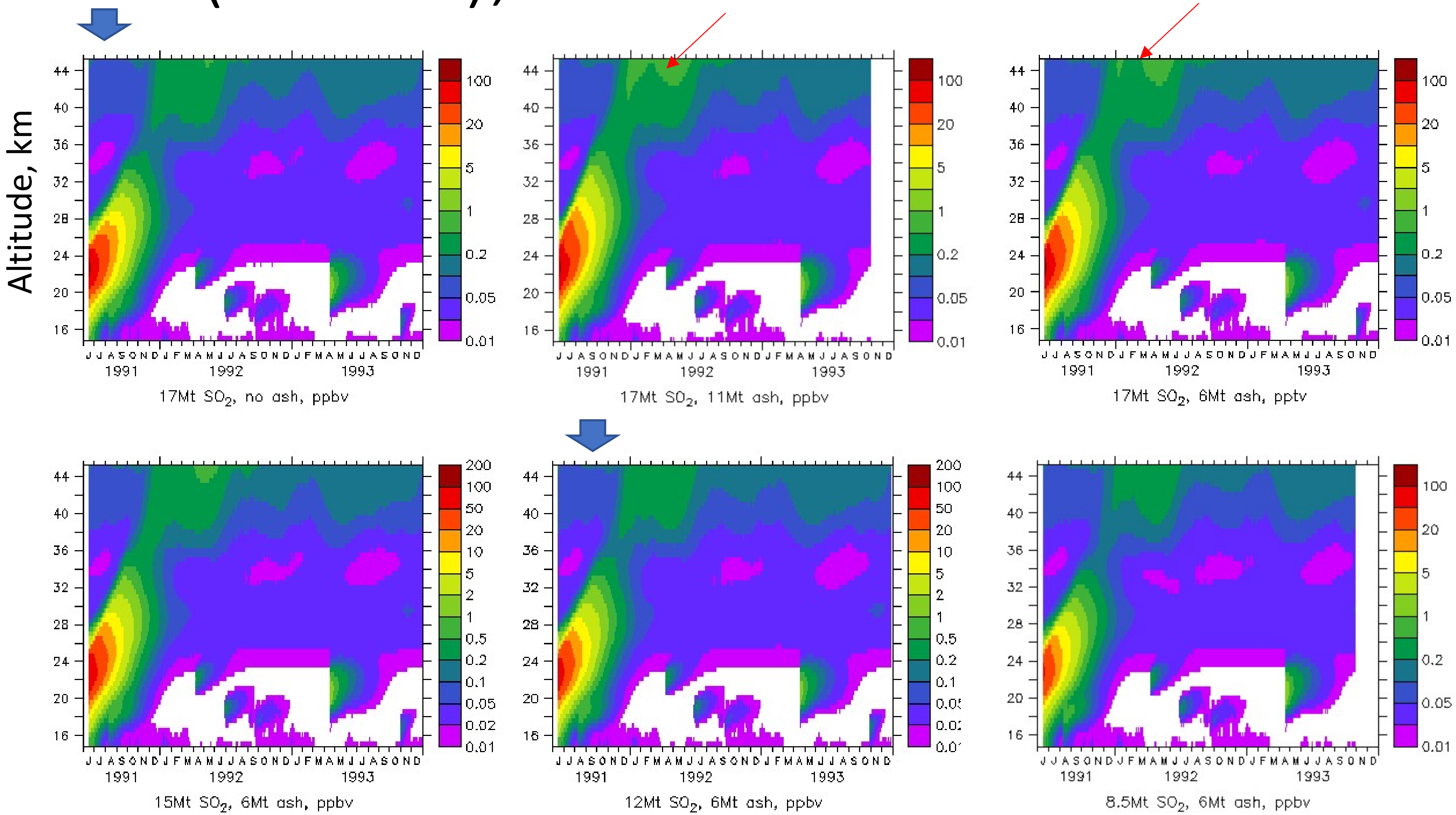
Model EMAC (V2.54 and V2.52, Jöckel et al., 2010, GMD; Brühl et al., 2018, ACP)

- GCM ECHAM5, Resolution T63/L90 (1.9° up to 1 Pa with internal Quasi-Biennial Oscillation, slightly nudged), meteorology nudged to ERA-Interim in troposphere (below 100hPa), observed transient SST.
- MECCA1 chemistry module with sulfur chemistry, scavenging by clouds.
- GMXE aerosol module (4 soluble and 3 insoluble modes with ISORROPIA chemistry, $\sigma_{nuc,ait}$=1.59, σ_{acc}=1.49, σ_{cs}=1.7; lower mode boundaries (r) nucleation 0.0005, aitken 0.006, accum 0.07, coarse 1.6 µm). Interactive with dynamics and chemistry, incl. photolysis and heterogeneous reactions.
- Radiative forcing calculated online, aerosol types: dust, organic and black carbon, sulfate, sea salt and aerosol water.
- Volcanic SO_2 and ash plumes derived as 3D fields from SAGE II L2 data (perturbation added at days of eruption, Pinatubo, Hudson, Cerro Negro, Spurr, Lascar), year 1990 for spinup.

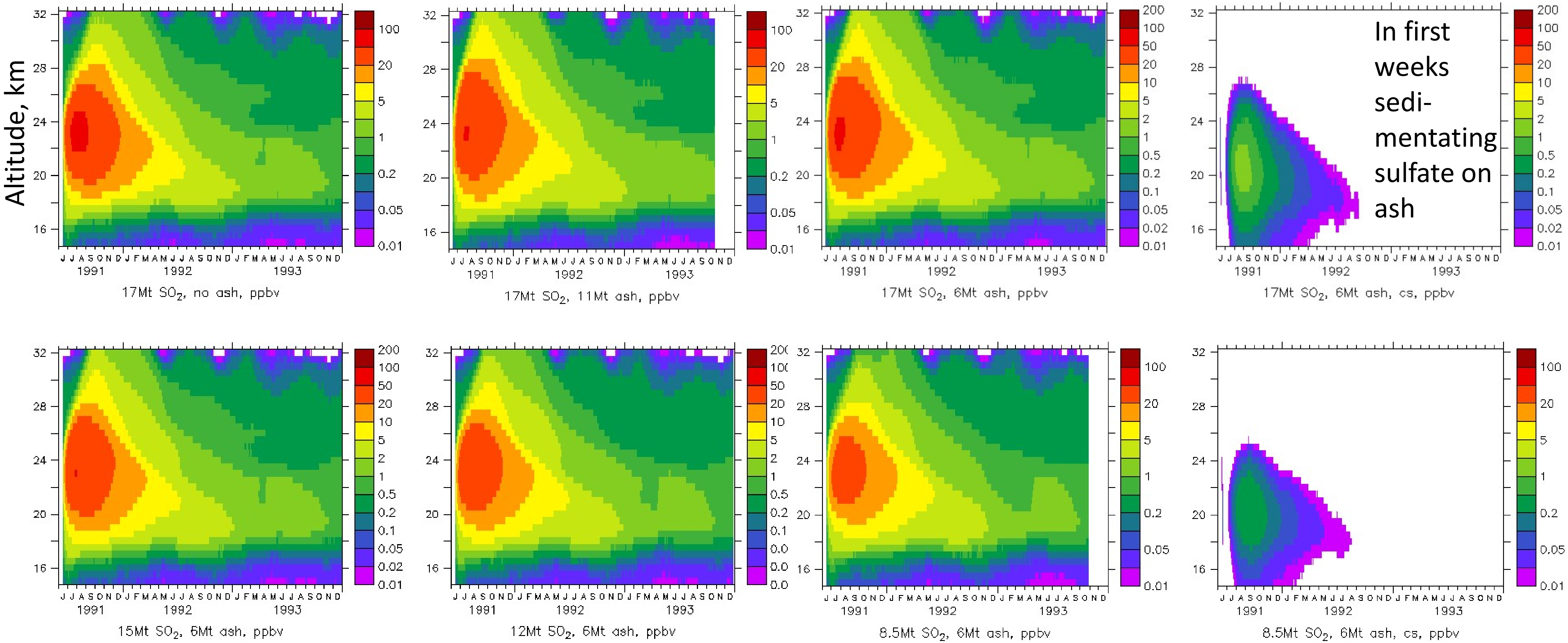
SO_2 (17 to 8.5Mt), without and with ash (accum), 20S-20N



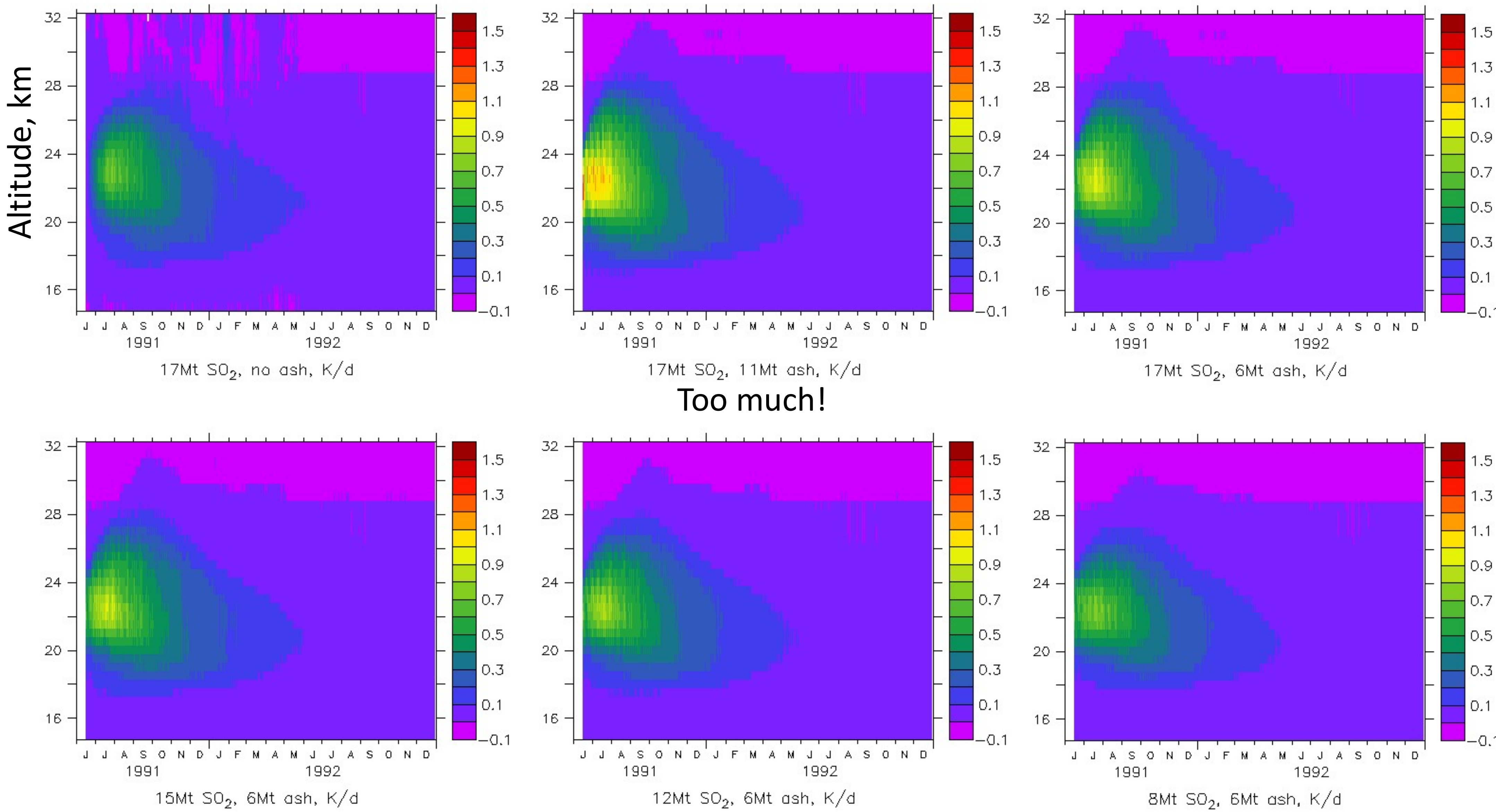
Radiative heating by ash causes faster lofting of SO_2 to upper stratosphere, compensating a reduction of the SO_2 emission from 17Mt to 12Mt there.

Sulfate in accumulation and coarse mode, 20S-20N

Reducing SO_2 emission to half leads to reduction of coarse mode fraction by factor of 8, much less loss by sedimentation.

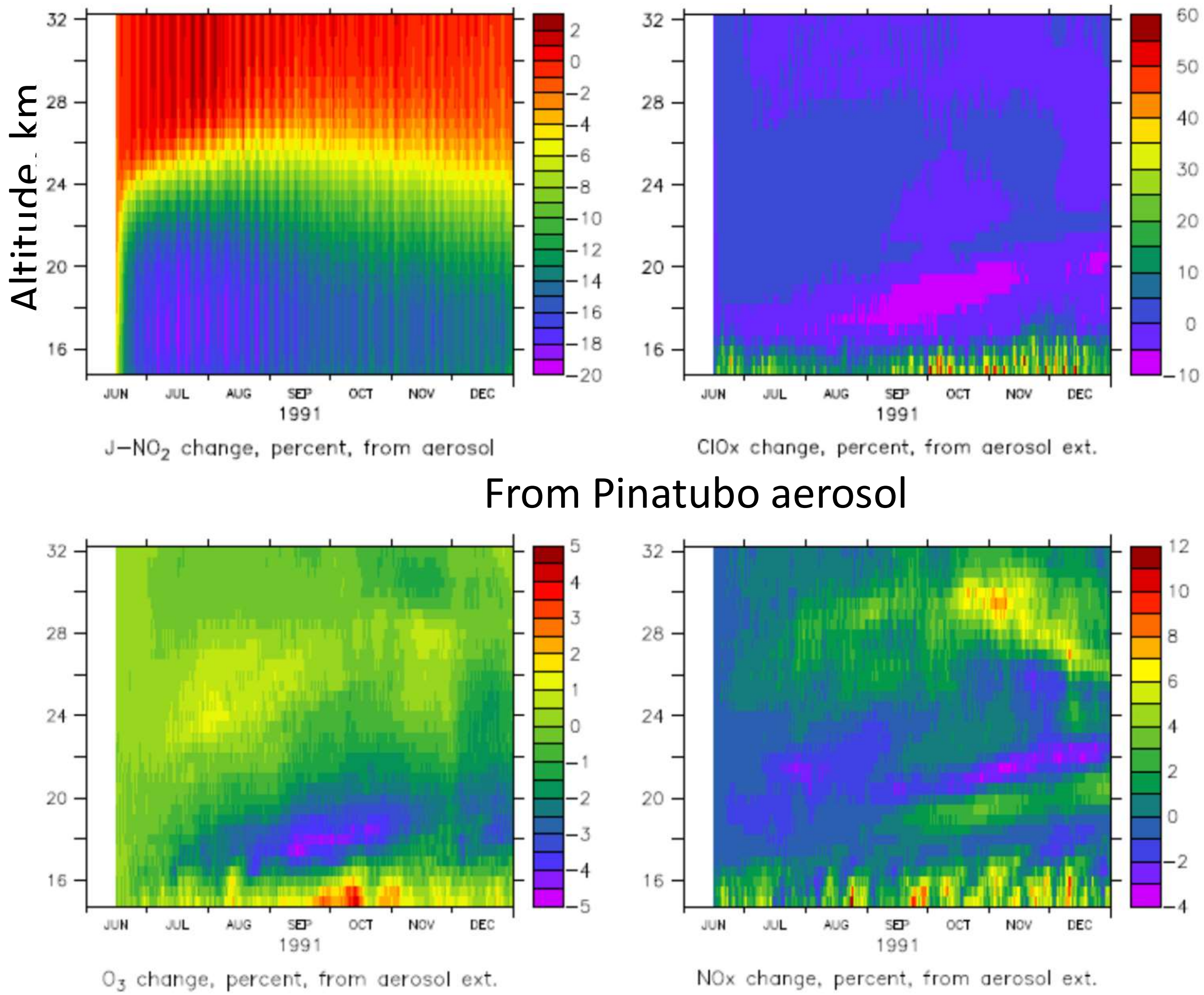


Instantaneous aerosol heating rates, 20S-20N

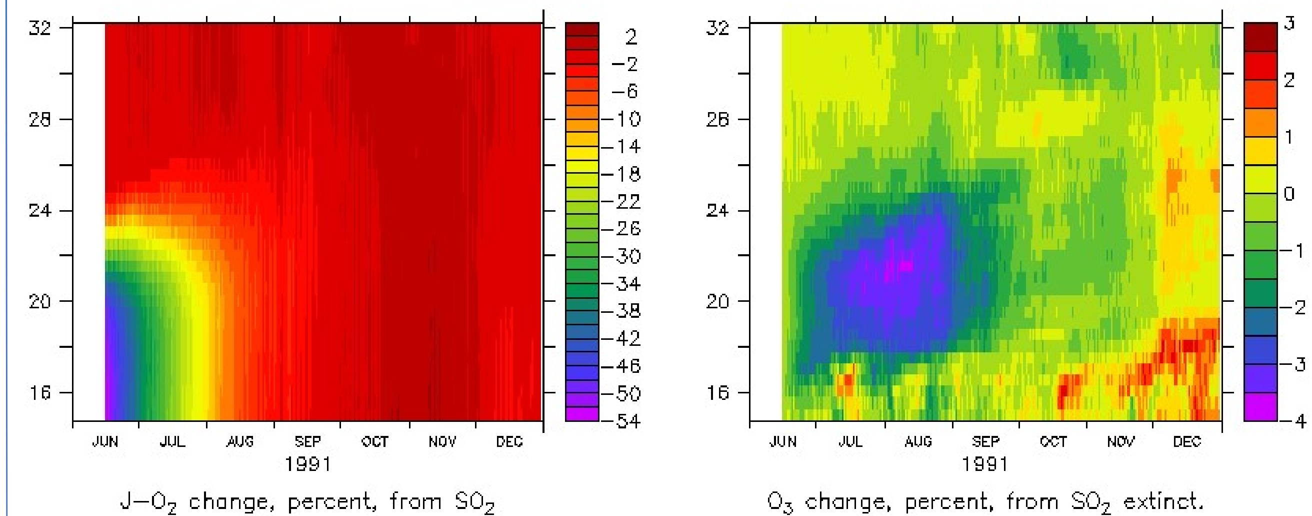


Shortwave + longwave, from radiation calls with and without aerosol

Effects of aerosol on photolysis, NOX and Ozone (left); effect of SO_2 extinction (right)



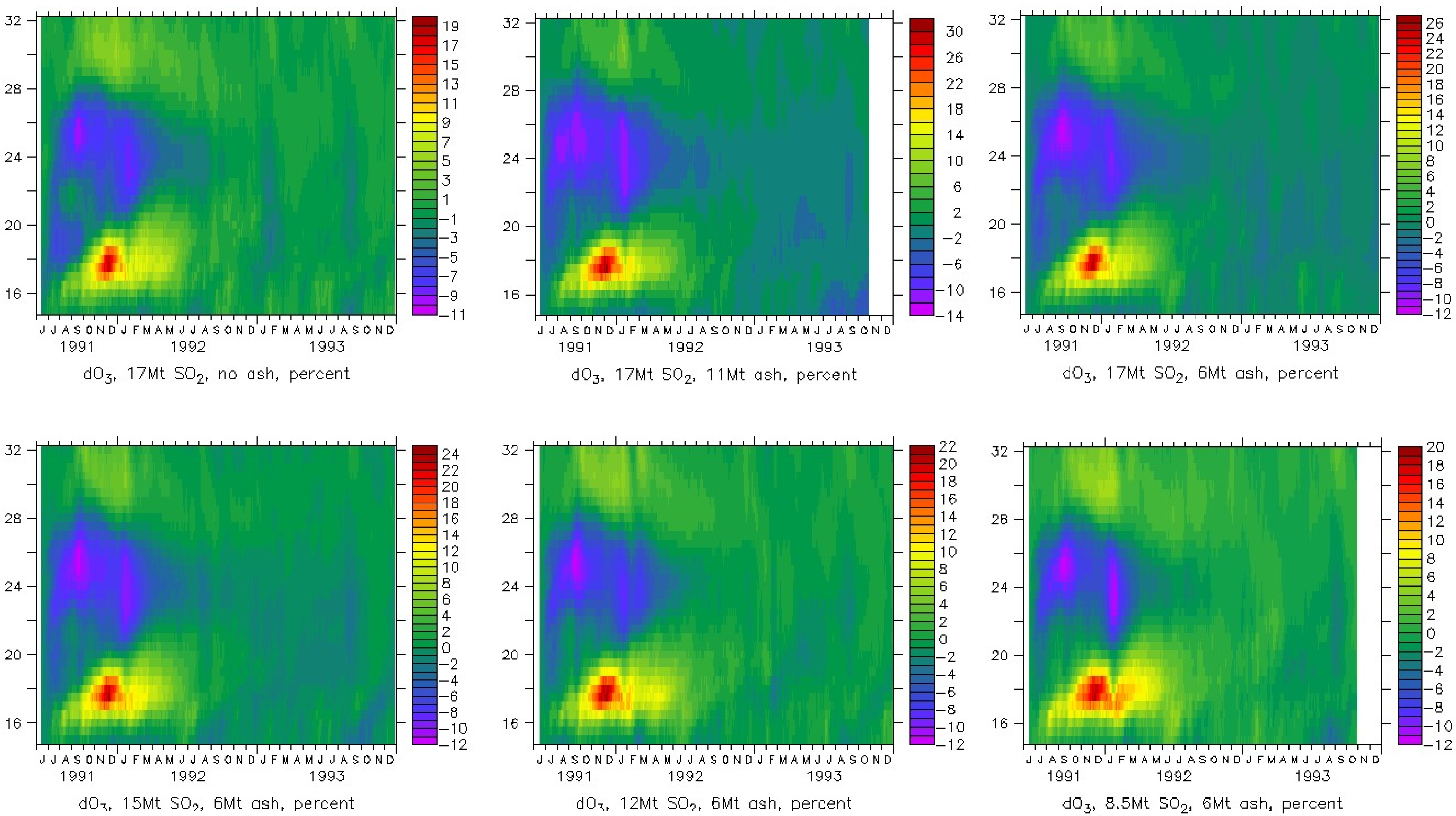
From Pinatubo aerosol



From Pinatubo SO_2 plume extinction, additional effect on photolysis

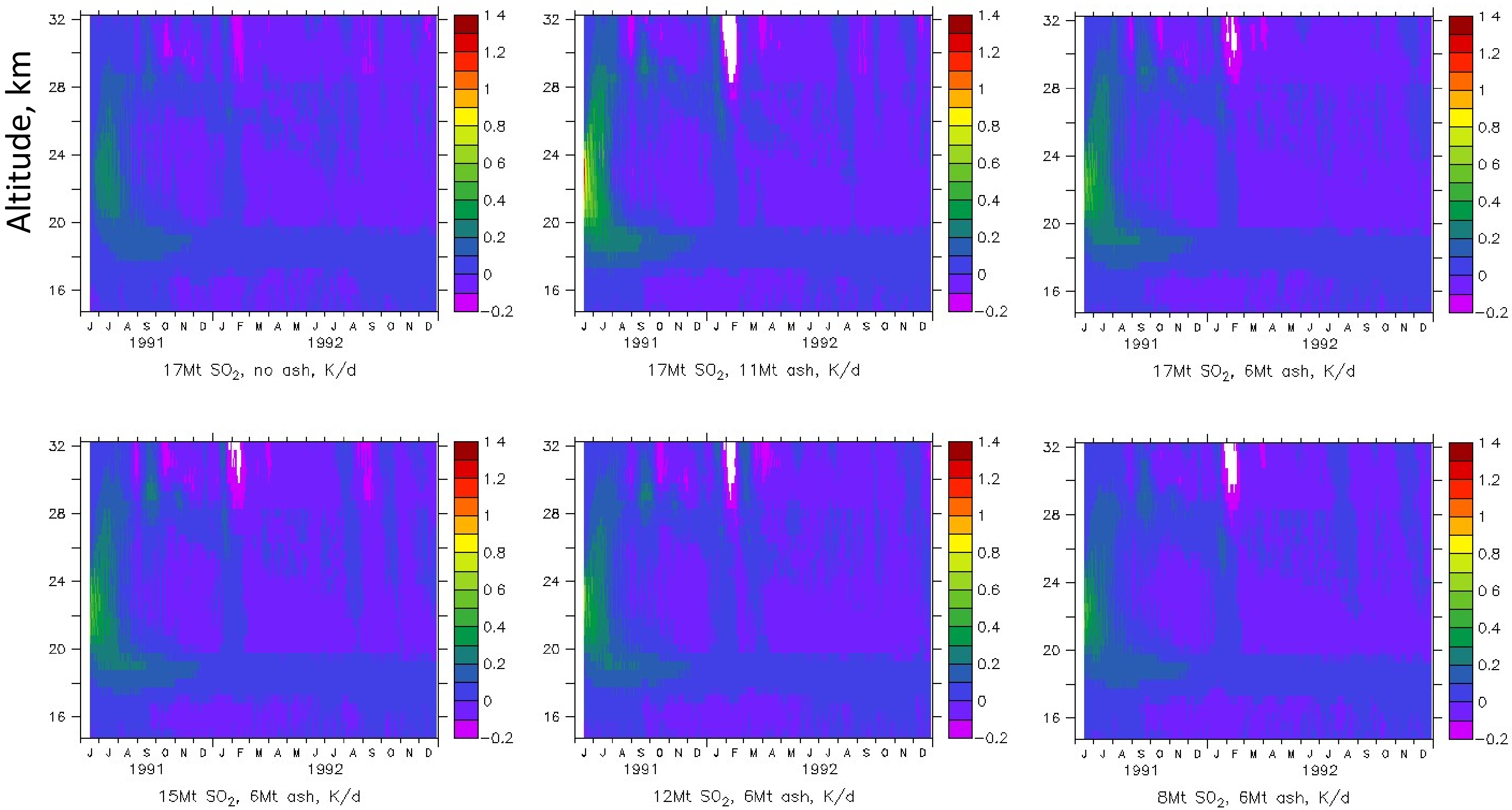
NO_2 increases below 18km, OH below 16km. Patterns of NOx and NO_2 changes differ because of heterogeneous chemistry. BrOx changes have similar patterns as ClOx changes

O_3 changes due to chemistry and lofting, 20S-20N



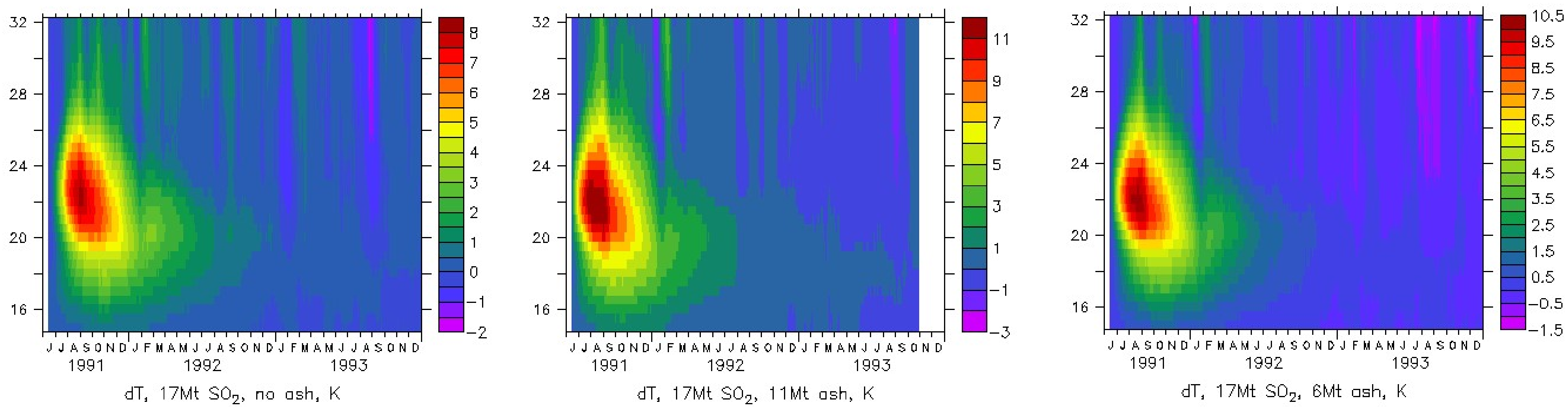
Ozone reductions in the early phase from SO_2 extinction, later from heterogeneous chemistry on the aerosol and reduction of photolysis rates by the aerosol. Lofting causes additional ozone reduction at about 25km. Increase below aerosol cloud due to ‘self healing’ by ozone column reduction above.

Heating rates of Pinatubo with indirect effects, 20S-20N

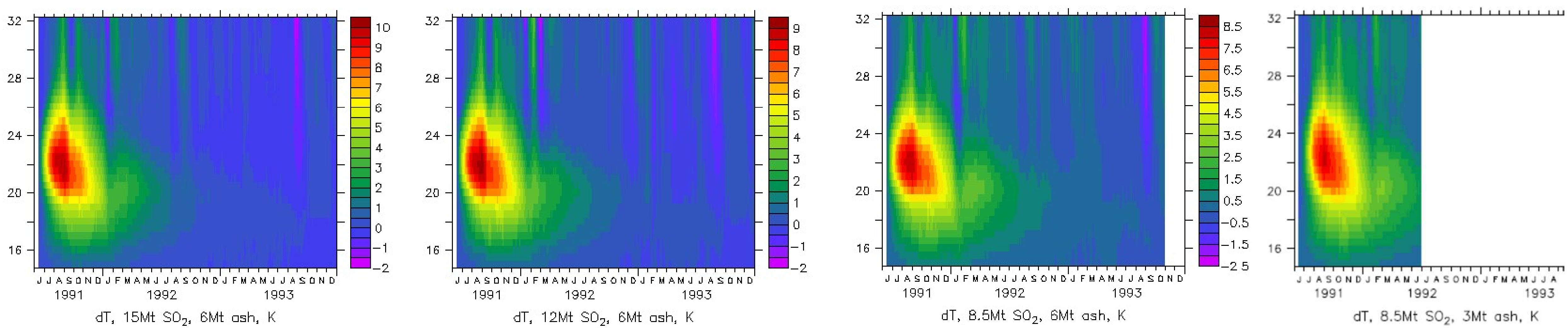


Indirect effects from ozone and temperature changes reduce heating rates substantially.

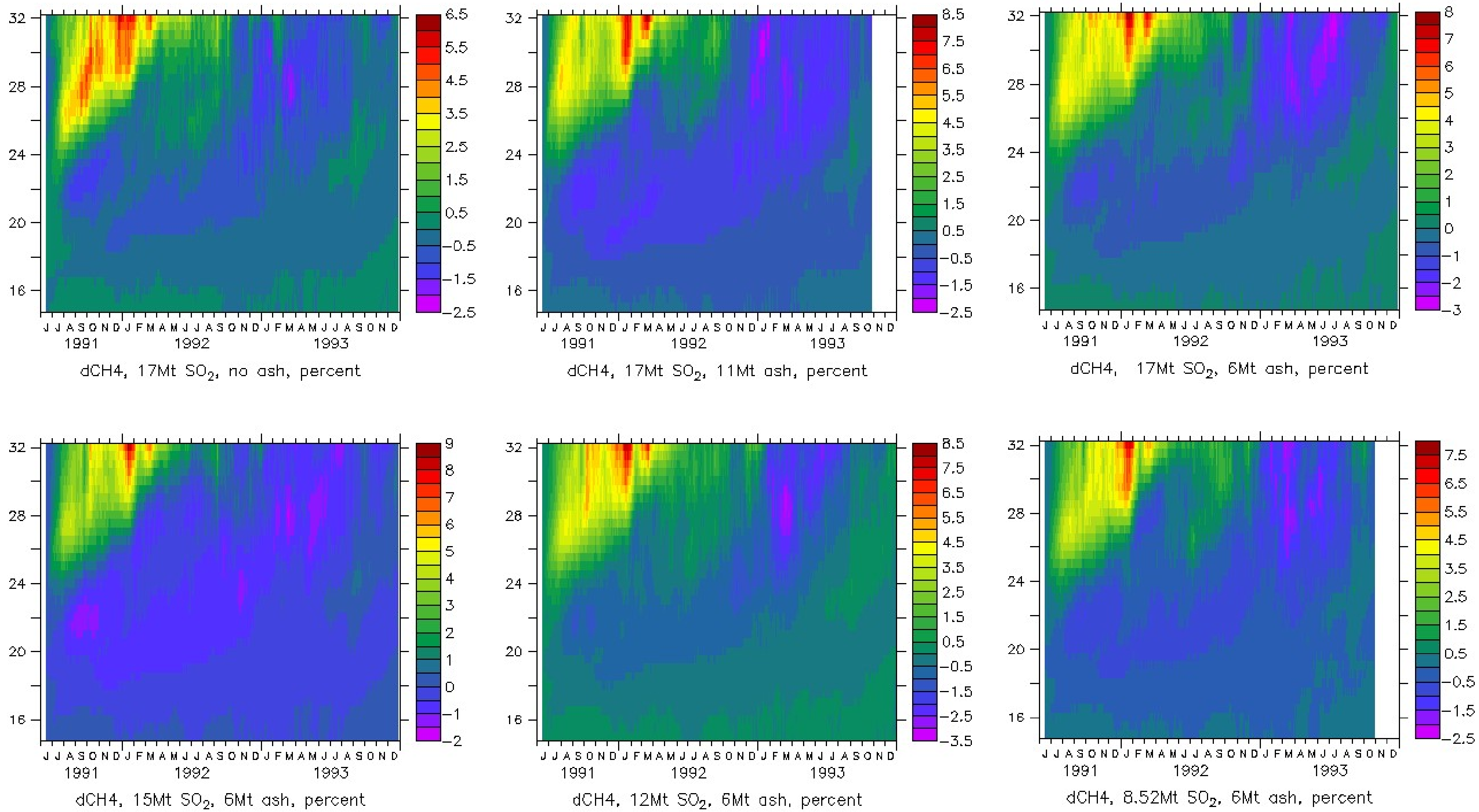
Temperature change due to Pinatubo, 20S-20N



Too much ash?



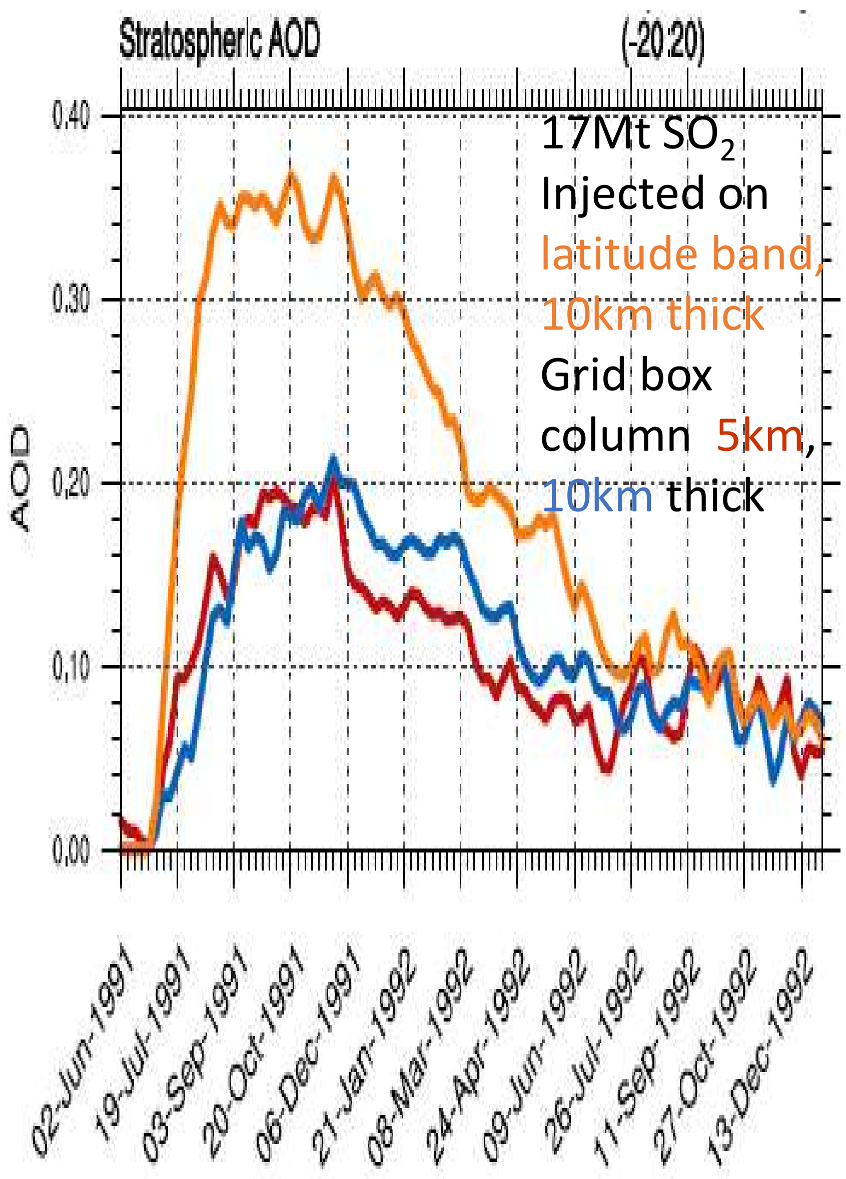
Methane change as example for dynamical tracer

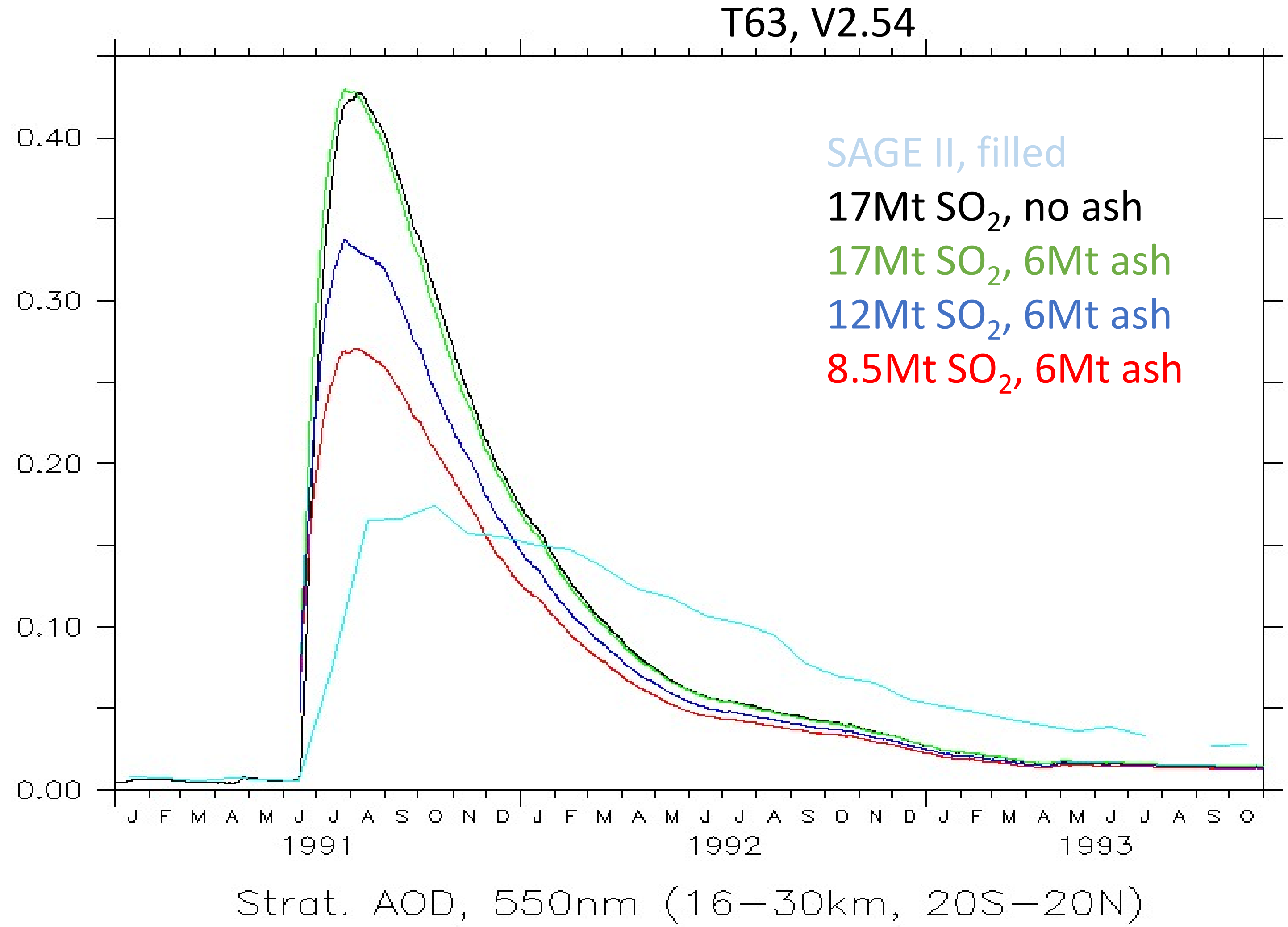


Methane increase by enhanced upwelling in middle stratosphere due to Pinatubo aerosol

Stratosph. Aerosol optical depth, 20S-20N

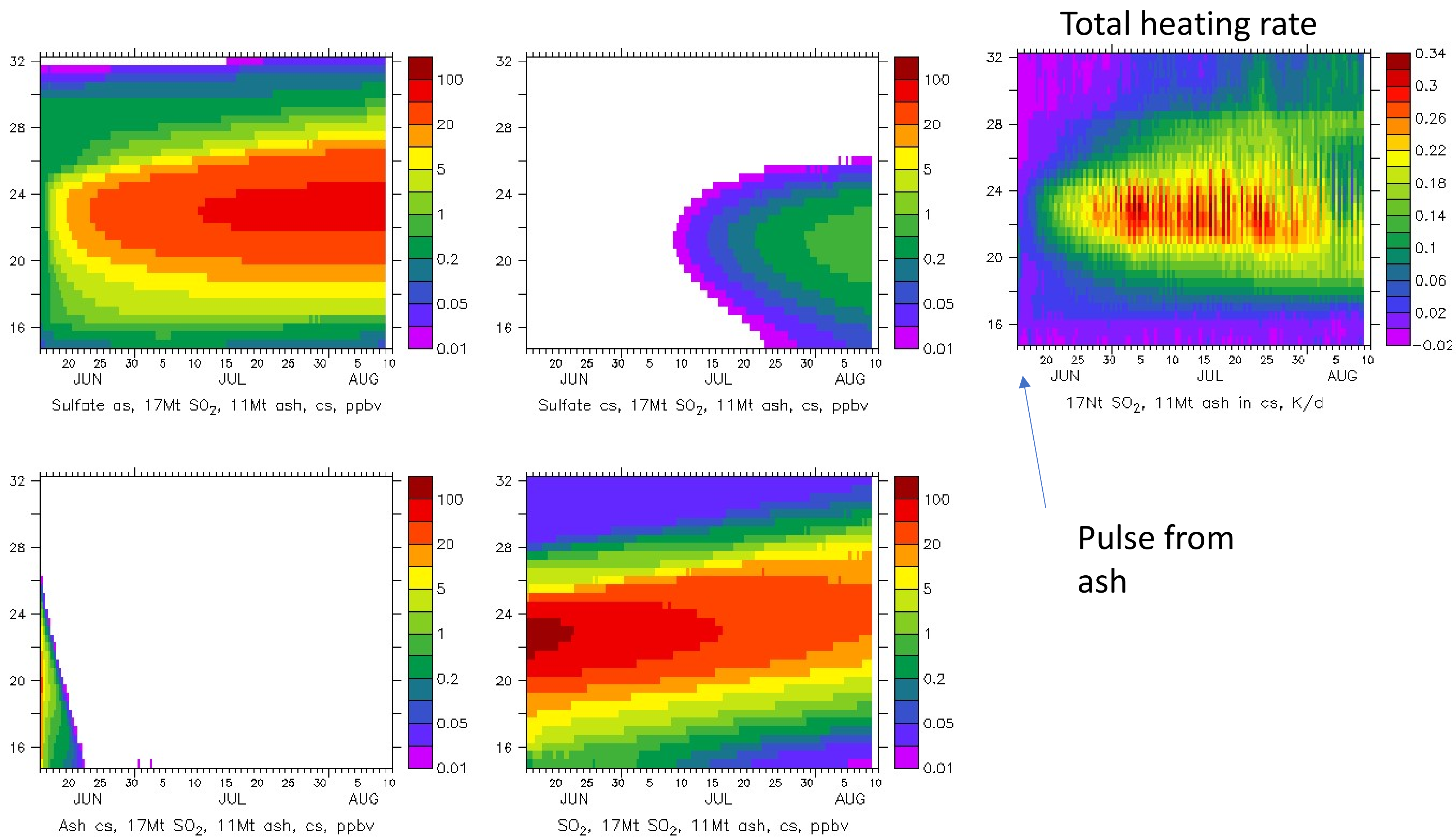
T42, V2.52, See also Abdelkader, presented at EGU 2020 for ash and Abdelkader, 2017; Zhu et al, 2020.





All injected as 3D plume.
Ash causes earlier increase of AOD

Ash injected in coarse mode with quick sedimentation



Conclusions

- Ozone changes via photolysis changes from aerosol and SO_2 extinction, and heterogeneous chemistry, reduce heating rates of Pinatubo aerosol
- Ash in accumulation mode enhances the upwelling due to radiative heating by aerosol
- Ash in coarse mode sedimentates in hours but causes a short heating pulse and reduces sulfate
- If injected as wide 3D-plume 17Mt SO_2 appears to be too much to reproduce observed AOD, after about 6 months AOD is similar with half of SO_2 (consistent with removal in plume when injected into a small volume or removal by heterogeneous reactions on ash)

References

- Abdelkader, M., Metzger, S., Steil, B., Klingmüller, K., Tost, H., Pozzer, A., Stenchikov, G., Barrie, L., and Lelieveld, J., 2017, *Atmos. Chem. Phys*., 17, 3799-3821.
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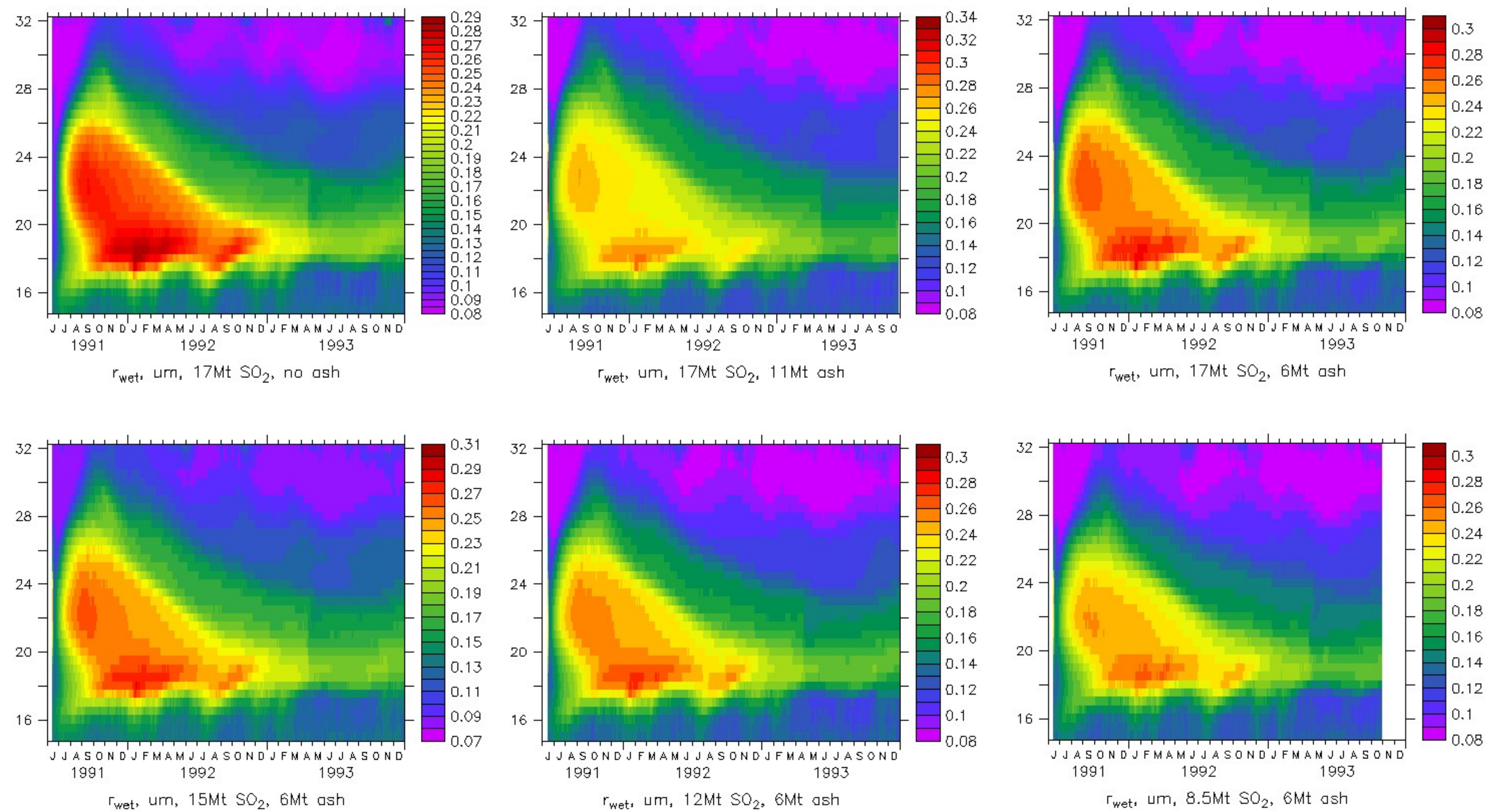
- Jöckel, P., Kerkweg, A., Pozzer, A., Sander, R., Tost, H., Riede, H., Baumgaertner, A., Gromov, S., and Kern, B., 2010, *Geosci. Model Dev.*, 3, 717–752.
- Y. Zhu , O. B. Toon, E. J. Jensen, C. G. Bardeen, M. J. Mills, M. A. Tolbert, P. Yu and S. Woods, 2020, *Nature Communications*, 11:4526.

Median wet radius (accum)



For area weighted effective radius multiply by 1.38. Biggest particles due to ash in first week, they grow into coarse mode with the tail of the distribution.