Effects of stratospheric volcanic aerosols on S2S prediction skill

OTSUKA Natsuko[1,*], SEKIGUCHI Ryohei[1], KOMORI Takuya[1] and TANAKA Taichu[2]

1. Climate Prediction Division, Japan Meteorological Agency, Tokyo, Japan
2. Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan
Email: n-otsuka@met.kishou.go.jp

1. Introduction

Volcanic eruptions significantly affect climate prediction due to related dispersion of aerosols that remain in the stratosphere for years (McCormic et al. 1995, Zambri et al. 2019). Stratospheric volcanic aerosols are generally produced by chemical reaction from gaseous sulfur dioxide (SO_2) to sulfuric acid (H_2SO_4) particles, and result in increased reflection of solar radiation back into space due to a higher Earth albedo along with absorption of upwelling infrared radiation. Therefore, stratosphere can be warmed by both radiation effects, while the troposphere can be cooled by solar radiation effect.

In light of the link between weather and climate predictions, volcanic aerosols can be considered to potentially influence skill in tropospheric temperature prediction on a sub-seasonal to seasonal (S2S) timescale. Accordingly, this study involved a revision of the radiation scheme in a case of the Mt. Pinatubo eruption with focus on radiative heating and resulting temperature changes due to volcanic aerosols in S2S prediction.

2. Experimental design with a revised radiation scheme

The Japan Meteorological Agency (JMA) is developing the next-generation Coupled Seasonal Ensemble Prediction System Version 3 (JMA/MRI-CPS3; CPS3), which consists of 60km atmospheric and eddy-permitting (0.25 deg.) ocean components. The current radiation scheme in CPS3 can deal with the direct effects of aerosols categorized into 5 types (sulfate, organics, black carbon, sea salt and dust) input as monthly climatological forcing data (JMA, 2019), but also needs to be able to handle stratospheric volcanic aerosols. The optical properties of such aerosols are determined via Mie scattering calculation, in which size distribution parameters and complex refractive indices are obtained from the OPAC database (Hess et al., 1998) for stratospheric sulfate droplets. The volcanic stratospheric aerosol information for the scheme is given as external monthly data as developed for CCMI-1 and CMIP6 (Revell et al., 2017). Monthly climatological tropospheric aerosols are pre-computed using JMA's MASINGAR global aerosol model (Tanaka et al. 2003). By May 1992, a year after the eruption of Mt. Pinatubo in the Philippines, volcanic aerosols were observed worldwide in the stratosphere (Figure 1). To verify prediction skill with the revised radiation scheme in this case, 13-member ensemble forecasting was conducted using CPS3.

3. Results

Results from a six-month forecast experiment (TEST) with an initial time of 00 UTC on 26 April 1992 using the revised radiation scheme were compared to those of a control experiment (CNTL) based on CPS3 configuration. As expected, due to the effects of stratospheric volcanic aerosols, both solar and infrared radiation caused stratospheric warming, while tropospheric cooling was calculated in relation to solar radiation (Figure 2).

The temperature difference on the S2S timescale was demonstrated in a six-month forecast experiment. Heating-rate differences of solar and infrared radiations make a stable condition with less heating rate of vertical diffusion in the lower troposphere, causing inactive deep convection and less cloud amount in the upper troposphere over the tropics (not shown). As a result, stratospheric temperatures increased and tropospheric temperatures decreased globally (Figure 3). Verification results against ERA5 reanalysis (Hersbach et al., 2020) show that TEST outperformed CNTL in temperature biases in the stratosphere and lower troposphere, although there is still room for improvement in the upper troposphere depending on the characteristics of physics in CPS3 (Figure 4). Overall, the revision of the radiation scheme shows encouraging and promising results for many aspects due to the stratospheric volcanic aerosols.

Reference

Hersbach, H., B.Bell, P. Berrisford, S. Hirahara, András Horányi1, J. Muñoz-Sabater, J. Nicolas, C. Peubey, R. Radu, D. Schepers, A. Simmons, C. Soci, S. Abdalla, X. Abellan, G. Balsamo, P. Bechtold, G. Biavati, J. Bidlot, M. Bonavita, G. De Chiara1, P. Dahlgren, D. Dee, M. Diamantakis, R. Dragani, J. Flemming, R. Forbes, M. Fuentes, A. Geer, L. Haimberger, S. Healy, R.J. Hogan1, E. Hólm, M. Janisková, S. Keeley, P. Laloyaux, P. Lopez, G. Radnoti, P. de Rosnay, I. Rozum, F. Vamborg, S. Villaume and J.-N. Thépaut, 2020: The ERA5 Global Reanalysis. Submitted to *Q. J. R. Meteorol. Soc.*

Hess, M., P. Koepke, and I. Schult, 1998: Optical properties of aerosols and clouds: The software package OPAC. *Bull. Amer. Meteor. Soc.*, 79, 831-844.

McCormic, M. P., L. W. Thomason, and C. R. Trepte, 1995: Atmospheric effects of the Mt Pinatubo eruption, *Nature*, 373, 399–404.

JMA, 2019: Outline of the operational numerical weather prediction at the Japan Meteorological Agency. Appendix to WMO technical progress report on the global data-processing and forecasting system and numerical weather prediction research. 188pp. Available online:
http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm

Revell, L. E., Stenke, A., Luo, B., Kremser, S., Rozanov, E., Sukhodolov, T., and Peter, T., 2017: Impacts of Mt Pinatubo volcanic aerosol on the tropical stratosphere in chemistry–climate model simulations using CCMI and CMIP6 stratospheric aerosol data, *Atmos. Chem. Phys.*, **17**, 13139-13150, doi:10.5194/acp-17-13139-2017.

Tanaka, T. Y., K. Orito, T. T. Sekiyama, K. Shibata, M. Chiba, and H. Tanaka, 2003: MASINGAR, a global tropospheric aerosol chemical transport model coupled with MRI/JMA98 GCM: Model description. *Papers in Meteorology and Geophysics*, 53(4), 119-138.

Zambri, B., A. Robock, M. J. Mills, and A. Schmidt, 2019: Modeling the 1783–1784 Laki Eruption in Iceland, Part II: Climate Impacts, *J. Geophys. Res.*, 124(13), 6770-6990.

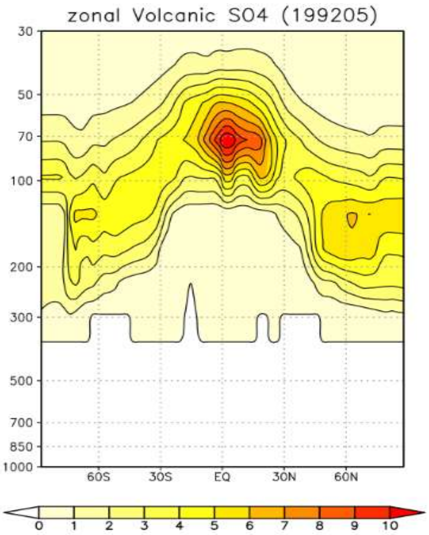

Figure 1. Zonal mean of volcanic aerosols [S mg/m2], averaged for May 1992.

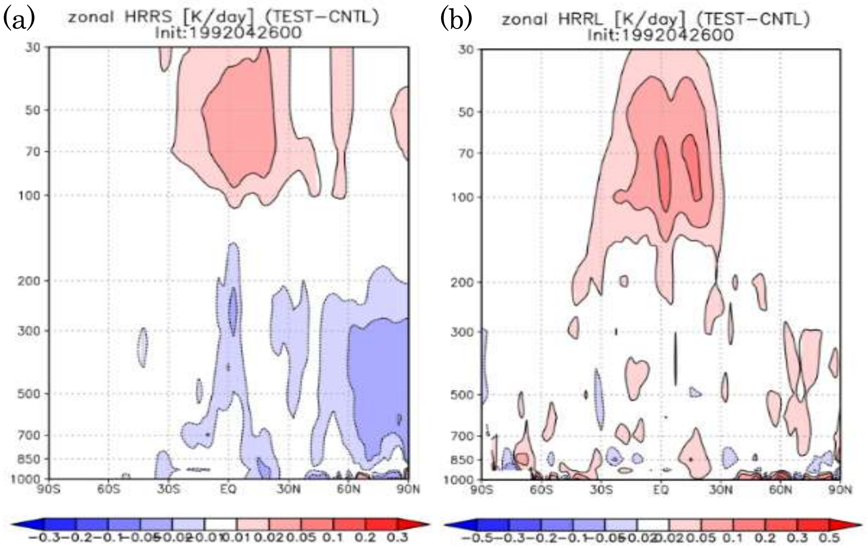

Figure 2. Zonal mean of heating rate differences [K/day] (TEST minus CNTL) of 13-member averaged (a) solar and (b) infrared radiation averaged over one month forecasts with an initial time of 00 UTC on 26 April 1992.

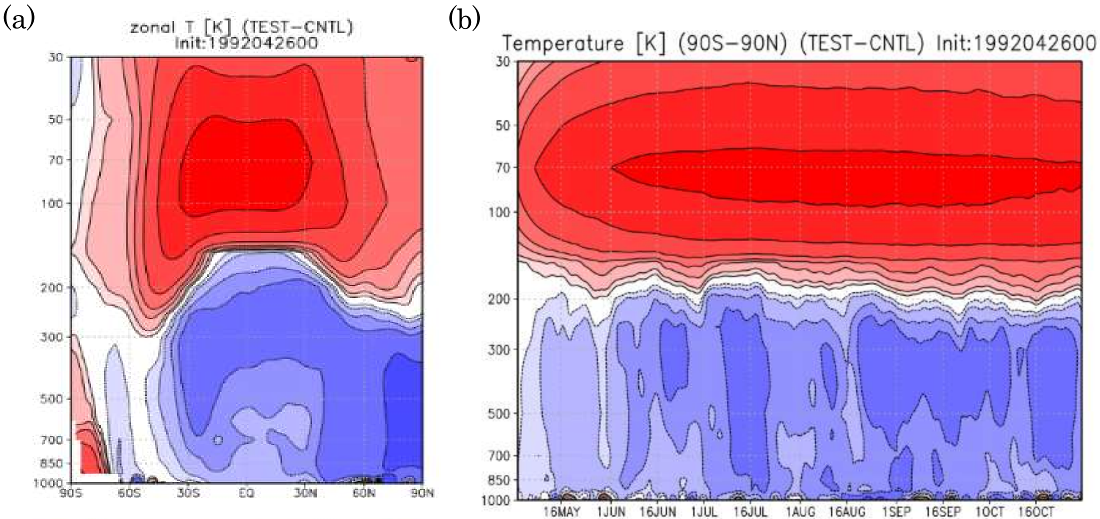

Figure 3. 13-member average temperature differences [K] (TEST minus CNTL) with (a) zonal mean and (b) pressure-time cross section of the global mean over six-month forecasting with an initial time of 00 UTC on 26 April 1992.

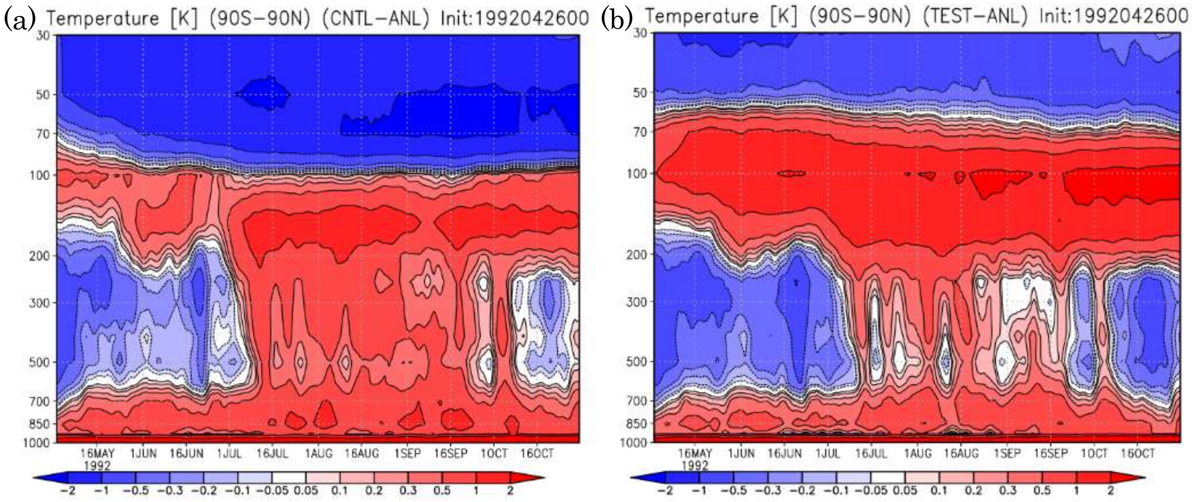

Figure 4. 13-member average pressure-time cross section of global average temperature errors [K] against ERA5 reanalysis for (a) CNTL and (b) TEST over six-month forecasting with an initial time at 00 UTC on 26th April 1992.