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Initial atmospheric conditions control transport of volcanic volatiles, forcing and impacts

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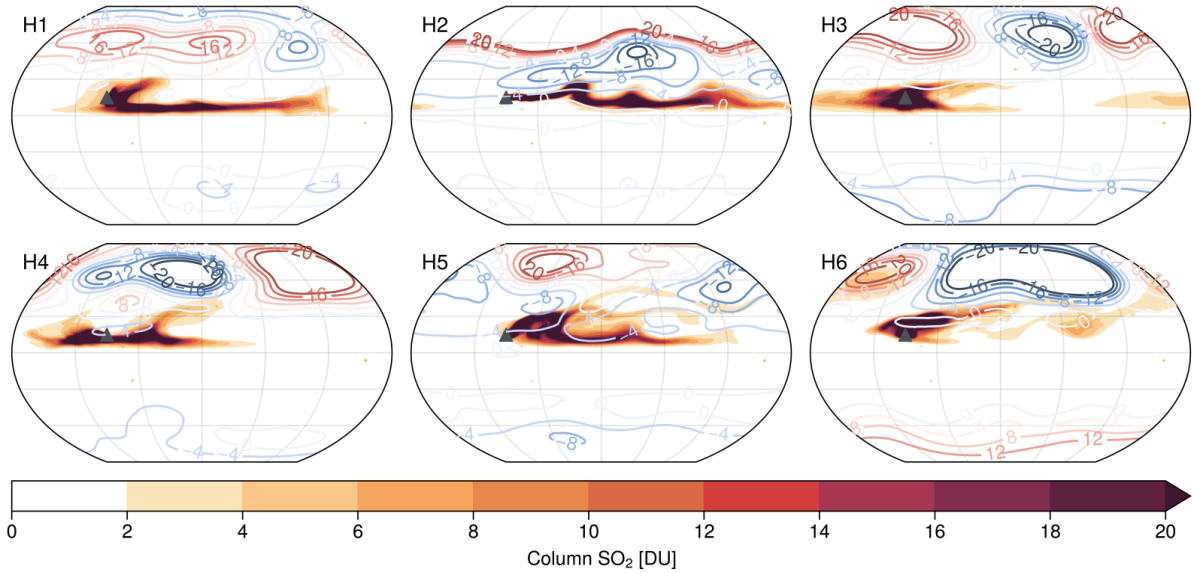

Figure S1. The first month longitudinal and latitudinal distribution of SO_2 column burden (filled contours) and geopotential height anomaly in units of geopotential decameters (contours) at 30 hPa after tropical eruptions in January for the six members of the baseline experiment. The gray triangle denotes the eruption latitude and longitude at 15° N and 91° W.

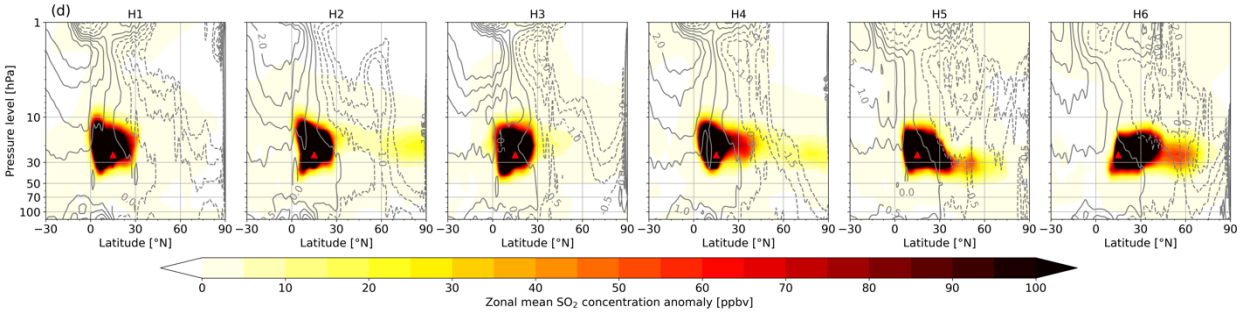

Figure S2. First month latitudinal and vertical distribution of SO_2 concentration anomaly (shades), and residual vertical velocity (w*, contours with an interval of 0.5 mm s−1) (d) in the stratosphere after tropical eruptions in January for six members of the baseline experiments. The red triangle indicates the eruption latitude at 15° N and the injection altitude at 24 km.

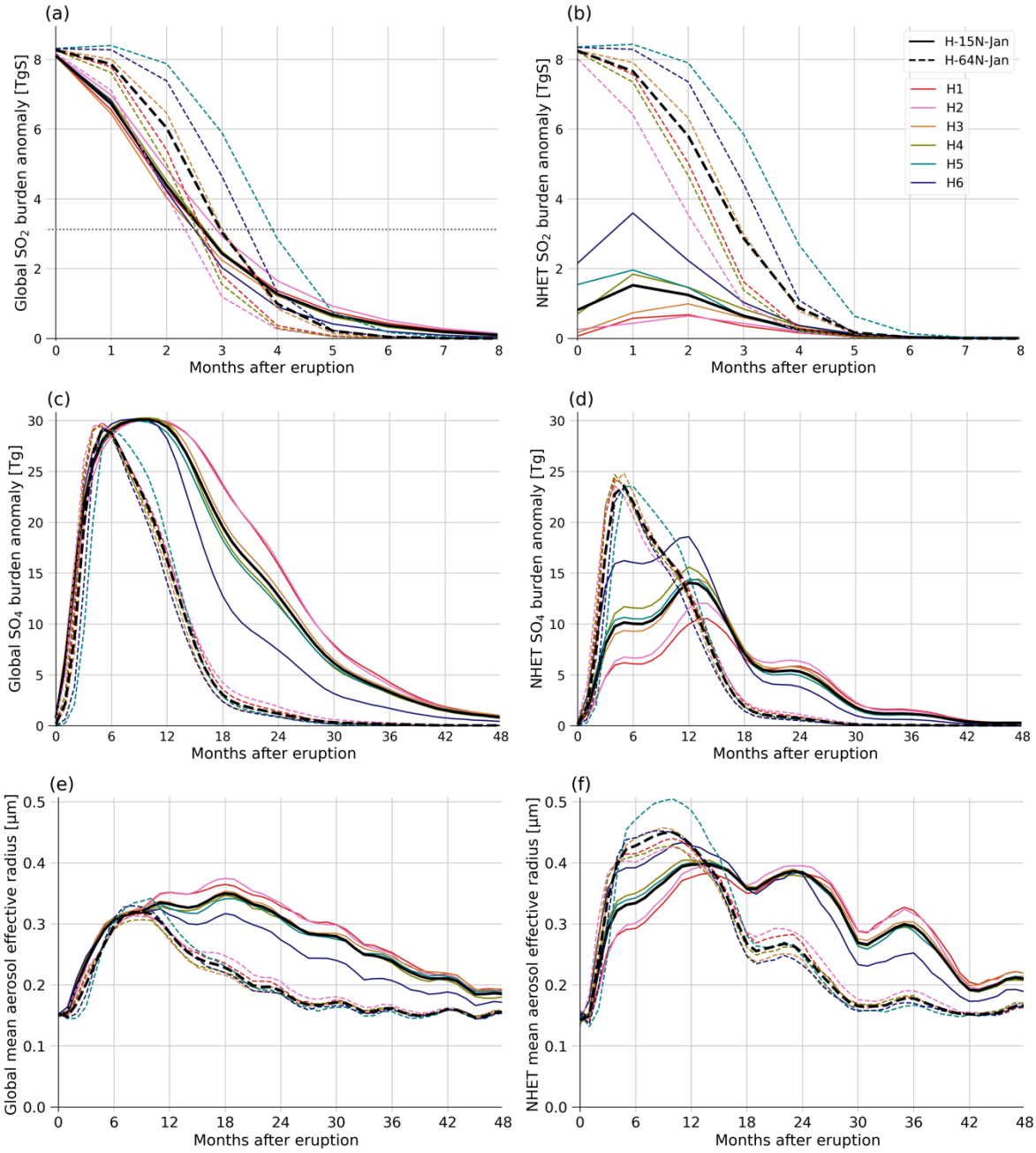

Figure S3. Global (left panel) and Northern Hemisphere extratropics (NHET [30 °N – 90 °N], right panel) SO_2 (a, b), SO_4 (c, d) burden anomaly and aerosol effective radius (R_{eff}, e, f). Solid lines and dashed lines are for tropical and NH extratropical eruptions, respectively. Different colors represent different ensemble member realizations. The black lines represent the ensemble means of the baseline experiments. The gray dotted horizontal line in (a) represents the e–folding of injected sulfur. Note the different axes in different subfigures.

Section 1:

Figure S3 shows time series of global and NHET SO_2, SO_4, aerosol effective radius (R_{eff}). The global SO_2 burden reduces faster in the first months after tropical eruptions (H–15N–Jan, solid lines) compared to NH extratropical eruptions (H–64N–Jan, dashed lines) with an average e–folding time of 2.6 months and 3 months, respectively (Fig. S2a). Along with the reduction of SO_2, SO_4 forms within the first post–eruption month. The maximum global SO_4 burden after tropical and NH extratropical eruptions is almost the same, reaching up to 30 Tg, 9 months after the tropical eruptions but 5 months after the NH extratropical eruptions (Fig. S3c). Differences in the transport of SO_2 lead to different peak timing of SO_4 after tropical and NH extratropical eruptions. As is reflected by the NHET SO_2 burden (Fig. Scb), after tropical eruptions (solid lines), SO_2 increases in the first 1 to 2 months and then decreases and disappears 4 to 5 months after the eruption, while showing a gradual transport of SO_2 from the tropics to NH high latitudes. Meanwhile, the NHET SO_4 burden exhibits a sharp increase in the first 4 to 5 months, followed by a decelerated increase, ultimately peaking around 12 months after the tropical eruptions (Fig. S3d). After the NH extratropical eruptions (dashed lines), due to confinement of the aerosols in the NHET region, global and NHET SO_2 and SO_4 burden show similar evolution (Fig. S3a–S3d). The duration of global SO_4 burden is affected by the transport of SO_2 from tropical to NH extratropical regions, which is longer for tropical eruptions over 48 months in contrast to NH extratropical eruptions over 30 months.

As shown in Figure 1, the initial atmospheric conditions control the transport of volcanic volatiles. The poleward transport of SO_2 and evolution of SO_4 in the NHET (Fig. S3b and S3d) show a large spread among the six ensemble members of tropical eruptions. More SO_2 is transported to NHET in H6 than in H1, leading to a higher peak NHET SO_4 burden in H6 than in H1. Meanwhile, the global SO_4 burden shows a faster reduction from its maximum in H6 than in H1 (Fig. S3c). In general, increased NHET transport after tropical eruptions is accompanied by a faster reduction of global SO_4 burden (Fig. S3c).

The aerosol grows through condensation and coagulation along the conversion of SO_2 to SO_4 in the stratosphere. In line with the conversion of SO_2 to SO_4, the global–mean SO_4 – mass–weighted mean effective radius (R_{eff}, Fig. S3e) increases faster after tropical eruptions compared to NH extratropical eruptions for the first 6 months. R_{eff} further increases 7–9 months after tropical eruptions when the peak has already been reached after NH extratropical eruptions, and it decreases slower after tropical eruptions compared to NH extratropical eruptions. This is similar for the NHET–mean R_{eff} (Fig. S3f) with a smaller but later peak after tropical eruptions compared to NH extratropical eruptions. This agrees with the varied lifetime of SO_2 and SO_4 burden (Fig. S3a–S3d). For tropical eruptions, it takes time for SO_2 to be transported northward, and the amount of SO_2 transported to the NHET region varies due to different initial atmospheric conditions (Fig. S3b). This is also reflected by different R_{eff} in different ensemble members. After tropical eruptions, the NHET–mean R_{eff} is larger in maximum, i.e., 0.43 μm in H6 compared to 0.38 and 0.39 μm in H1 and H2, this difference range of 0.05 is approximately 15 times of the 2σ-variability of the control run without volcanic injections. The NHET-mean R_{eff} decreases faster in H6 than in H1 and H2 (Fig. S3f), indicating a faster removal of larger aerosols with larger gravitational settling velocity than for small aerosols. In line with this, less SO_4 is available outside of NHET regions. Thus, the maximum global–mean R_{eff} is 0.31 μm in H6, smaller than 0.36 μm in H1 and 0.37 μm in H2 (Fig. S3e). For NH extratropical eruptions, the aerosol size grows continuously with SO_2 concentrated in the NHET region.

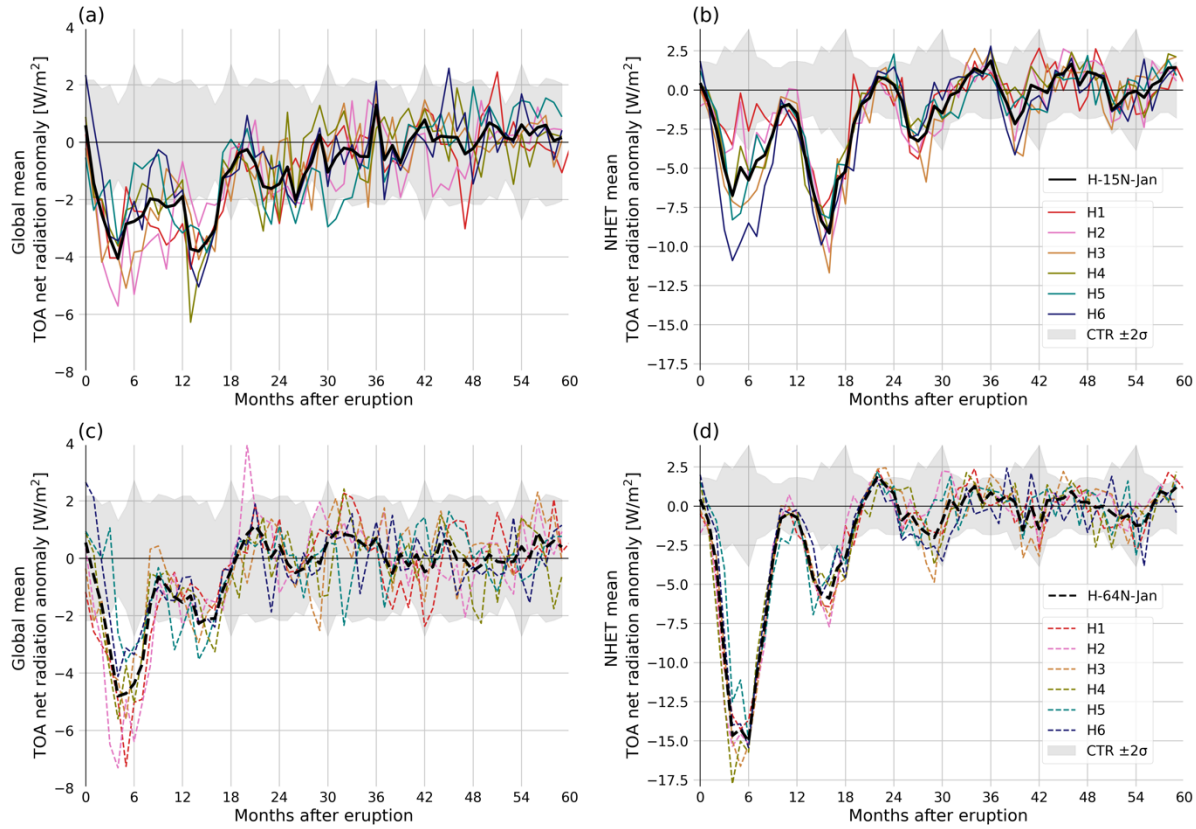

Figure S4. Global (left panel) and Northern Hemisphere extratropic (NHET, right panel) mean net radiation at the top of the atmosphere in full-sky conditions. Solid lines and dashed lines are for tropical (a-b) and NH extratropical (c-d) eruptions, respectively. ferent colors represent different ensemble member realizations. The black lines represent the ensemble member means of the baseline experiments. The gray shades represent two standard deviations of the control run. Note the different y-axes between the left and right panels.

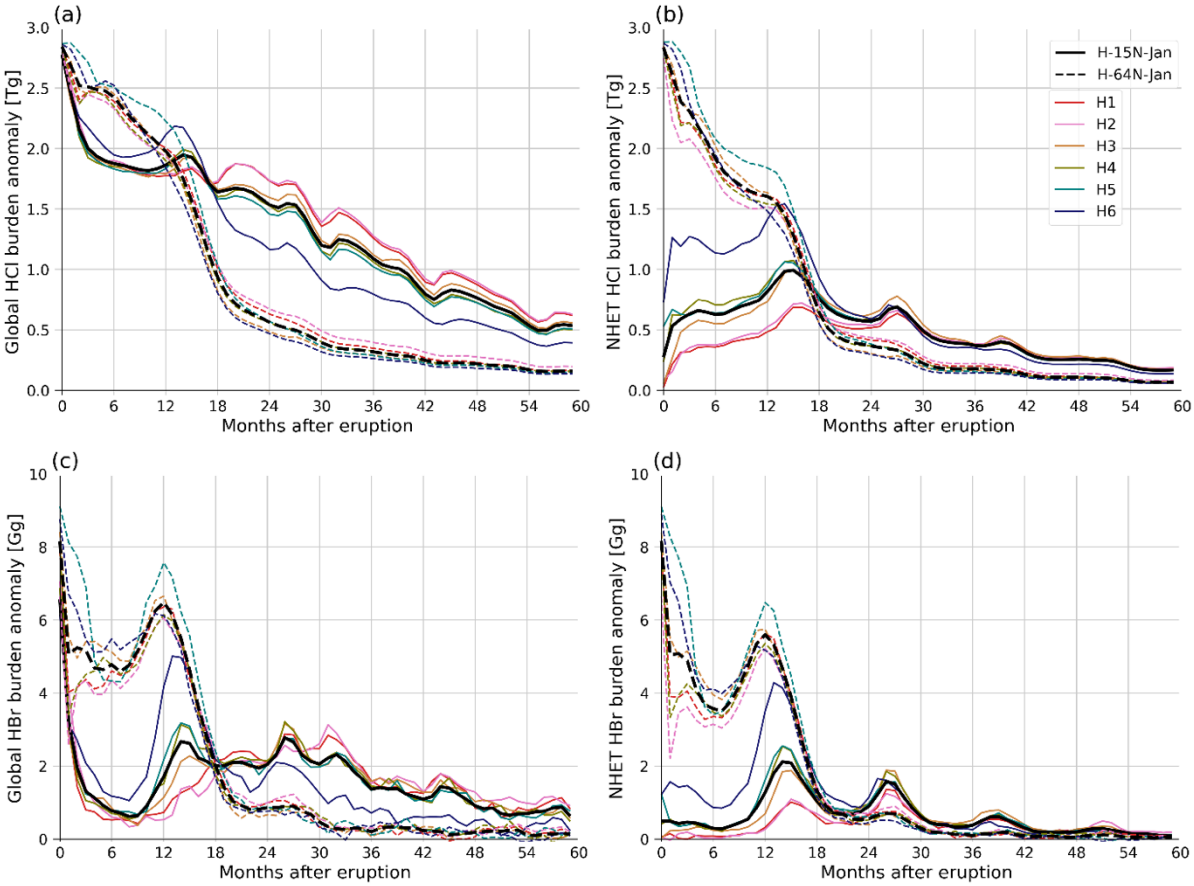

Figure S5. Global (left panel) and Northern Hemisphere extratropics (NHET [30 °N – 90 °N], right panel) HCl (a, b) and HBr (c, d) burden anomaly. Solid lines are variations after tropical eruptions, while dashed lines are variations after NH extratropical eruptions. Different colors represent different ensemble member realizations. The black lines represent the ensemble means of the baseline experiments.

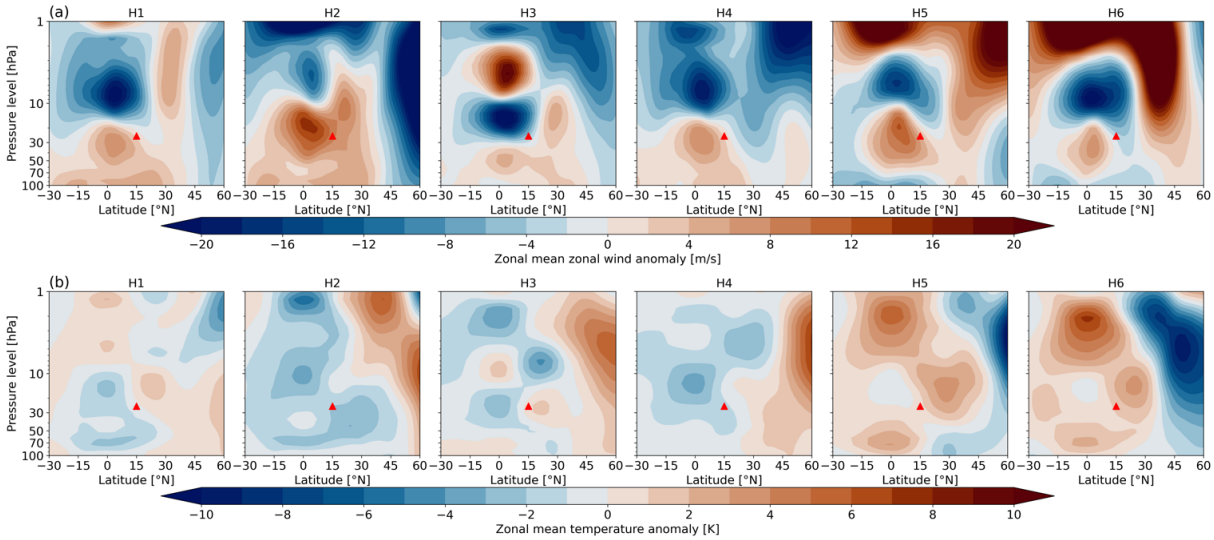

Figure S6. The first month latitudinal and vertical distribution of zonal mean zonal wind (a) and temperature (b) anomaly in six members of the baseline experiments. The red triangle indicates the level and latitude of the tropical volcanic injections.

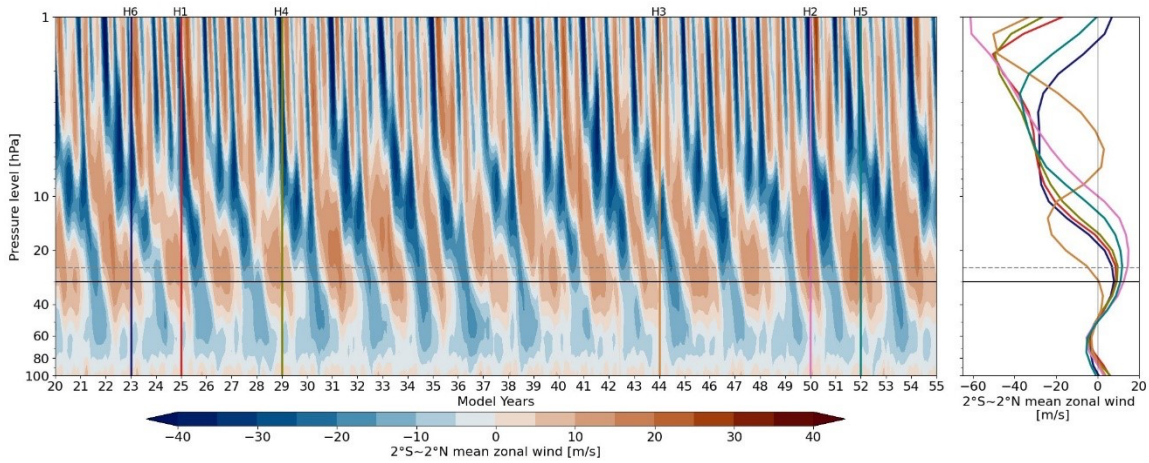

Figure S7. Initial Quasi-Biennial Oscillation (QBO) state indicated by the equatorial (2º S to 2º N) mean zonal wind at 30 hPa (black horizontal line). The grey horizontal line indicates the volcanic volatile injection altitude at 25 hPa. Vertical lines denote the selected initial QBO state in January for six members of the baseline experiment, whose wind profiles are displayed in the right panel, with colors corresponding to those shown in Figures 1 to 4.

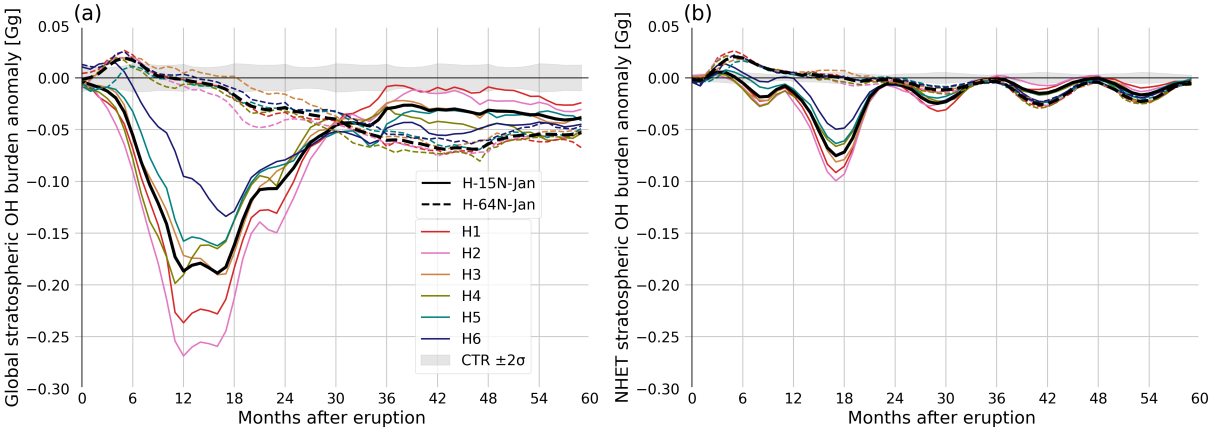

Figure S8. Global (a) and Northern Hemisphere extratropic (NHET, b) stratospheric OH burden anomaly. Solid lines and dashed lines are for tropical and extratropical eruptions, respectively. Different colors represent different ensemble member realizations. The black lines represent the ensemble member means of the baseline experiments.