

기후분과 [P-140]

Hemispheric Asymmetry of Asian Monsoon responses to Stratospheric Aerosol Injection: Moisture and Energy Perspectives

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Stratospheric Aerosol Injection (SAI) has been proposed to offset global warming by reflecting incoming solar radiation through sulfur dioxide (SO₂) injections into the stratosphere. While SAI may be effective in cooling global mean temperature, its regional climate impacts remain highly uncertain, particularly for monsoon systems that affect billions of people. This study investigates the Asian summer monsoon (JJAS) response to lower-stratospheric SO₂ injections (~22 km) at seven latitudes from 45°S to 45°N (15° intervals), using simulations from CESM2-WACCM6 under SSP2-4.5 scenario.

Moisture budget analysis reveals that rainfall changes are primarily governed by moisture convergence associated with the low-level jet (LLJ). Northern Hemisphere (NH) injections reduce the hemispheric temperature gradient, weakening the LLJ and low-level convergence, and leading to suppressed rainfall across the monsoon domain. In contrast, Southern Hemisphere (SH) injections strengthen the LLJ and convergence, thereby enhancing monsoon precipitation.

An energetic perspective also explains these asymmetric responses. Hemispheric imbalances in net atmospheric energy input (NEI) are compensated by cross-equatorial atmospheric energy transport (AET), which affects the Intertropical Convergence Zone (ITCZ) position. NH injections decrease outgoing longwave radiation, which drives an energy surplus in the SH. This surplus induces northward AET and a southward ITCZ shift, displacing the convergence zone away from the Asian monsoon domain and reducing rainfall. Conversely, SH injections mainly reduce net shortwave input, producing an energy deficit in the SH, southward AET and a northward ITCZ shift, which places the ITCZ over the monsoon domain and intensifies rainfall. Together, the moisture and energetic perspectives provide a dynamically consistent explanation for the opposite monsoon rainfall responses to NH versus SH injections.

Keywords: Stratospheric Aerosol Injection (SAI), Asian Summer Monsoon, Moisture budget, Atmospheric energy transport (AET), Intertropical Convergence Zone (ITCZ)