

Support information

Revealing the Mechanistic Linkage Between QBO-Modulated Stratospheric Dynamics and Southern Tibetan Plateau Precipitation by Stratospheric $^{10}\text{Be}/^7\text{Be}$ Isotope Characteristics

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Supporting figures:

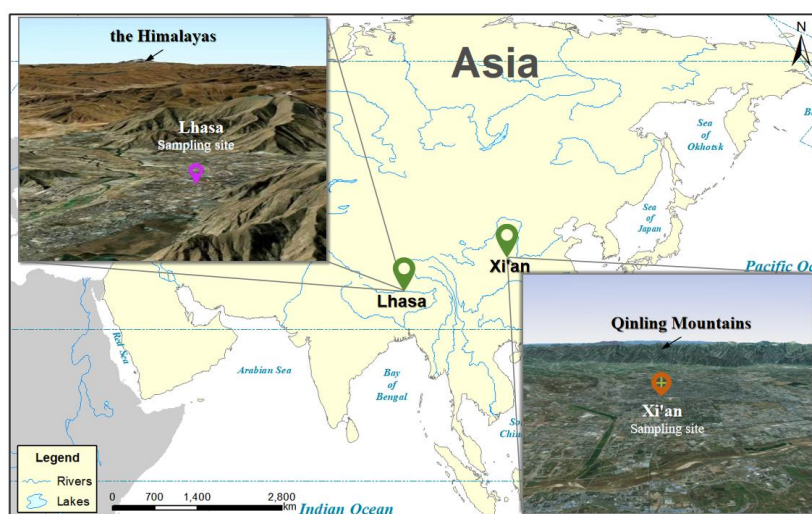


Fig. S1 Geographical environment of each sampling point. Maps data: © Google Earth 2025, images: © Esri, HERE, Garmin, FAO, NOAA, USGS | Powered by Esri.

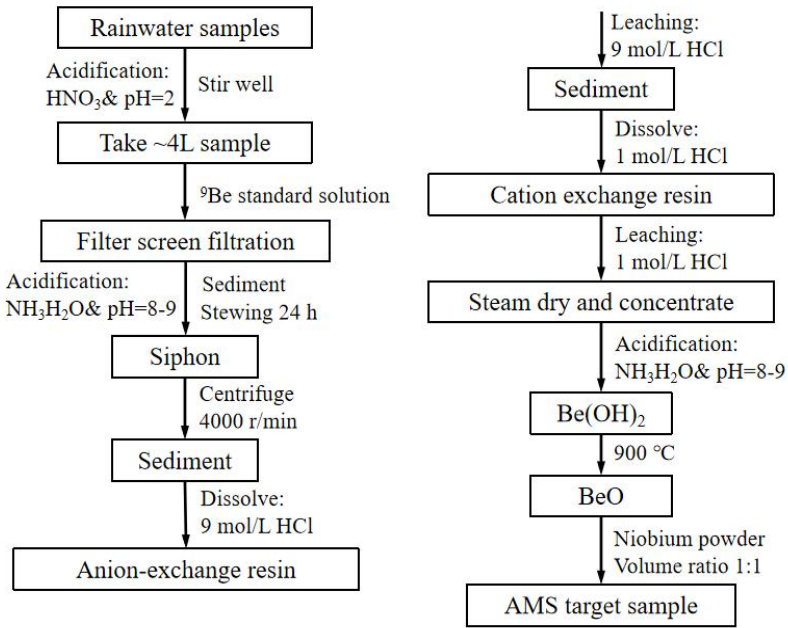


Fig.S2 Extraction and purification scheme of beryllium in rainwater samples

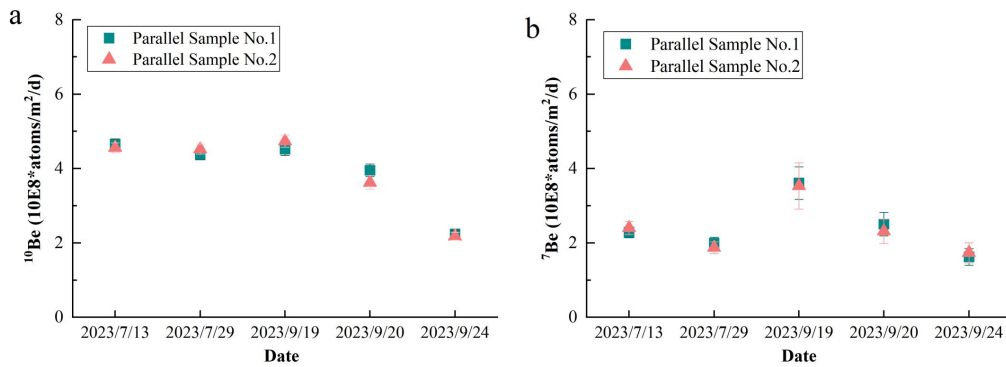


Fig.S3 Parallel test results of rainwater samples. ^{10}Be (a), ^7Be (b)

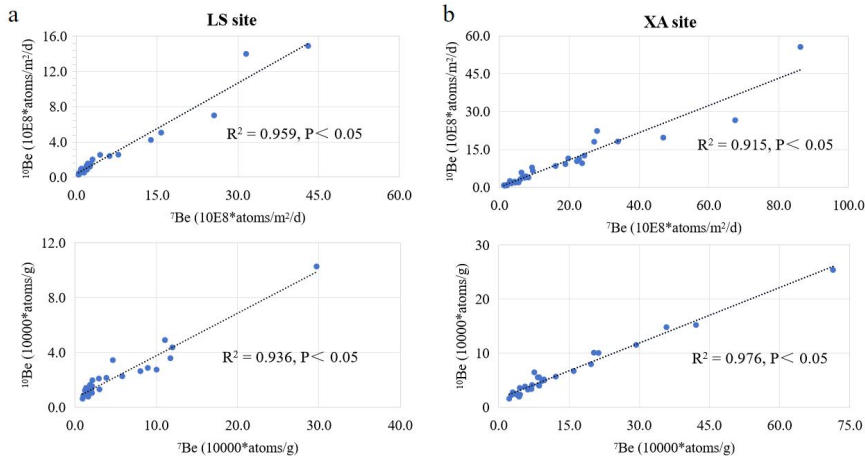


Fig.S4 Correlation between the fluxes and concentrations of ^7Be and ^{10}Be in precipitation in Lhasa (a) and Xi'an (b)

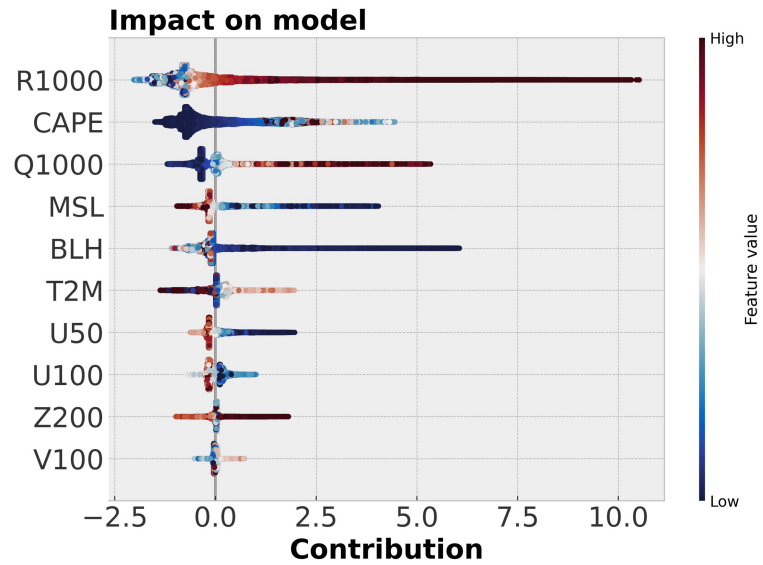


Fig.S5 Drivers and contribution of total precipitation revealed by machine learning. The contribution is expressed in SHapley Additive exPlanations (SHAP) value, which measure the impact of each driver factor induced by meteorological conditions change on the model output. R1000, relative humidity at 1000hPa (%); CAPE, convectively available potential energy (J/kg); Q1000, specific humidity at 1000hPa (g/kg); MSL, mean sea level pressure (hPa); BLH (m); T2M, air temperature at 2 meters (K); U50, zonal wind at 50hPa (m/s); U100, zonal wind at 100 meters (m/s); Z200, geopotential height at 200hPa (m); V200, meridional wind at 100 meters (m/s).

Supporting tables:

Table S1. Measurement results of atmospheric ^7Be and ^{10}Be concentration and flux, as well as $^{10}\text{Be}/^7\text{Be}$ ratio in rainfall at Lhasa station

| Time | Rain collection | ^{10}Be concentration | Error | ^7Be concentration | Error | $^{10}\text{Be}/^7\text{Be}$ | Error | Daily rainfall | ^{10}Be flux | Error | ^7Be flux | Error |
|-----------|-----------------|--------------------------------|-------|-----------------------------|-------|------------------------------|-------|----------------|---------------------------------------|-------|---------------------------------------|-------|
| | volume (L) | (10^4 atoms·g $^{-1}$) | | (10^4 atoms·g $^{-1}$) | | | | mm | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | |
| 2022/7/21 | 4 | 2.117 | 0.133 | 1.541 | 0.416 | 1.373 | 0.361 | 10.1 | 1.557 | 0.420 | 1.387 | 0.364 |
| 2022/7/26 | 6 | 2.945 | 0.173 | 2.101 | 0.340 | 1.402 | 0.211 | 1.4 | 0.294 | 0.048 | 0.196 | 0.030 |
| 2022/8/3 | 6 | 1.525 | 0.087 | 0.878 | 0.348 | 1.737 | 0.683 | 29 | 2.545 | 1.010 | 5.039 | 1.980 |
| 2022/8/19 | 6 | 1.784 | 0.125 | 1.050 | 0.365 | 1.698 | 0.578 | 8.3 | 0.872 | 0.303 | 1.410 | 0.480 |
| 2022/8/31 | 4 | 1.598 | 0.140 | 1.074 | 0.427 | 1.488 | 0.577 | 18.8 | 2.019 | 0.803 | 2.797 | 1.085 |
| 2022/9/3 | 5 | 1.713 | 0.139 | 1.179 | 0.416 | 1.453 | 0.498 | 11 | 1.297 | 0.457 | 1.598 | 0.548 |
| 2022/9/4 | 4.25 | 1.037 | 0.104 | 0.865 | 0.349 | 1.200 | 0.469 | 6.5 | 0.562 | 0.227 | 0.780 | 0.305 |
| 2022/9/7 | 5 | 1.379 | 0.071 | 1.165 | 0.156 | 1.183 | 0.146 | 6.1 | 0.711 | 0.095 | 0.722 | 0.089 |
| 2022/9/8 | 5.95 | 1.857 | 0.151 | 1.644 | 0.316 | 1.129 | 0.196 | 2.8 | 0.460 | 0.088 | 0.316 | 0.055 |
| 2022/9/12 | 5.2 | 1.225 | 0.161 | 1.237 | 0.599 | 0.990 | 0.461 | 7.9 | 0.977 | 0.473 | 0.782 | 0.365 |
| 2022/9/13 | 4.5 | 0.944 | 0.084 | 0.633 | 0.317 | 1.490 | 0.734 | 5 | 0.317 | 0.158 | 0.745 | 0.367 |
| 2022/9/14 | 4.5 | 1.376 | 0.115 | 1.422 | 0.404 | 0.967 | 0.263 | 6.2 | 0.882 | 0.251 | 0.600 | 0.163 |
| 2022/9/25 | 4.5 | 1.756 | 0.155 | 1.014 | 0.361 | 1.732 | 0.597 | 15.3 | 1.551 | 0.552 | 2.650 | 0.914 |
| 2022/9/27 | 4.5 | 1.365 | 0.138 | 1.051 | 0.365 | 1.298 | 0.431 | 7.4 | 0.778 | 0.270 | 0.961 | 0.319 |
| 2022/9/29 | 4.5 | 2.150 | 0.122 | 1.981 | 0.366 | 1.085 | 0.191 | 2.2 | 0.436 | 0.081 | 0.239 | 0.042 |
| 2023/6/13 | 4 | 29.703 | 0.439 | 10.291 | 0.215 | 2.886 | 0.043 | 14.5 | 14.922 | 0.312 | 4.185 | 0.062 |
| 2023/6/14 | 4 | 11.068 | 0.332 | 4.916 | 0.209 | 2.251 | 0.068 | 28.5 | 14.011 | 0.594 | 6.416 | 0.192 |
| 2023/6/15 | 12 | 4.659 | 0.154 | 3.452 | 0.162 | 1.350 | 0.045 | 2.5 | 0.863 | 0.040 | 0.337 | 0.011 |
| 2023/6/16 | 12 | 11.981 | 0.202 | 4.377 | 0.104 | 2.737 | 0.046 | 1.2 | 0.525 | 0.013 | 0.328 | 0.006 |

| | | | | | | | | | | | | |
|-----------|-----|--------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|
| 2023/6/19 | 4.5 | 3.868 | 0.185 | 2.155 | 0.278 | 1.795 | 0.215 | 2.7 | 0.582 | 0.075 | 0.485 | 0.058 |
| 2023/6/20 | 6 | 10.036 | 0.271 | 2.755 | 0.254 | 3.643 | 0.321 | 25.5 | 7.025 | 0.648 | 9.290 | 0.819 |
| 2023/6/21 | 7 | 11.738 | 0.293 | 3.590 | 0.264 | 3.270 | 0.226 | 11.8 | 4.236 | 0.312 | 3.858 | 0.267 |
| 2023/7/3 | 6 | 8.957 | 0.251 | 2.880 | 0.302 | 3.110 | 0.314 | 17.6 | 5.069 | 0.531 | 5.473 | 0.552 |
| 2023/7/24 | 5.5 | 3.013 | 0.141 | 1.319 | 0.280 | 2.285 | 0.474 | 6.5 | 0.857 | 0.182 | 1.485 | 0.308 |
| 2023/8/3 | 5.5 | 2.095 | 0.145 | 1.053 | 0.236 | 1.990 | 0.425 | 9.2 | 0.969 | 0.217 | 1.830 | 0.391 |
| 2023/8/4 | 5.5 | 1.635 | 0.122 | 0.781 | 0.123 | 2.094 | 0.291 | 15.5 | 1.210 | 0.191 | 3.245 | 0.451 |
| 2023/8/7 | 6 | 5.819 | 0.153 | 2.272 | 0.369 | 2.562 | 0.411 | 10.6 | 2.408 | 0.391 | 2.715 | 0.436 |
| 2023/8/8 | 5 | 8.049 | 0.205 | 2.646 | 0.410 | 3.042 | 0.465 | 9.7 | 2.566 | 0.398 | 2.951 | 0.451 |
| 2023/8/25 | 10 | 2.022 | 0.103 | 1.333 | 0.177 | 1.517 | 0.185 | 10.5 | 1.400 | 0.185 | 1.593 | 0.195 |

Table S2. Measurement results of atmospheric ^7Be and ^{10}Be concentration and flux, as well as $^{10}\text{Be}/^7\text{Be}$ ratio in rainfall at Xi'an station

| Time | Rain collection | | | ^{10}Be concentration | | | | ^7Be concentration | | | | Daily rainfall | | | | ^{10}Be flux | | | | ^7Be flux | | | |
|-----------|-----------------|--------------------------------|-------|--------------------------------|-------|------------------------------|-------|-----------------------------|---------------------------------------|-------|---------------------------------------|----------------|----------------|---------------------------------------|-------|---------------------------------------|-------|--|--|--------------------|--|--|--|
| | volume | ^{10}Be concentration | Error | ^7Be concentration | Error | $^{10}\text{Be}/^7\text{Be}$ | Error | Daily rainfall | ^{10}Be flux | Error | ^7Be flux | Error | Daily rainfall | ^{10}Be flux | Error | ^7Be flux | Error | | | | | | |
| | (L) | (10^4 atoms·g $^{-1}$) | | (10^4 atoms·g $^{-1}$) | | | | mm | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | | mm | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | | (10^8 atoms·m $^{-2}$ ·d $^{-1}$) | | | | | | | |
| 2023/4/2 | 40 | 3.655 | 0.189 | 2.456 | 0.452 | 1.488 | 0.263 | 3.5 | 0.860 | 0.158 | 0.521 | 0.092 | | | | | | | | | | | |
| 2023/4/19 | 27 | 5.627 | 0.324 | 3.874 | 0.664 | 1.453 | 0.234 | 17 | 6.586 | 1.129 | 2.469 | 0.399 | | | | | | | | | | | |
| 2023/4/20 | 17 | 9.297 | 0.220 | 4.910 | 0.377 | 1.894 | 0.138 | 17.3 | 8.494 | 0.651 | 3.276 | 0.239 | | | | | | | | | | | |
| 2023/4/21 | 4.5 | 20.340 | 0.382 | 10.130 | 0.674 | 2.008 | 0.128 | 11.2 | 11.346 | 0.755 | 2.249 | 0.143 | | | | | | | | | | | |
| 2023/5/5 | 53 | 8.522 | 0.225 | 4.163 | 0.437 | 2.047 | 0.208 | 2.5 | 1.041 | 0.109 | 0.512 | 0.052 | | | | | | | | | | | |
| 2023/5/6 | 10 | 16.019 | 0.305 | 6.724 | 0.526 | 2.382 | 0.181 | 29.3 | 19.701 | 1.541 | 6.980 | 0.530 | | | | | | | | | | | |
| 2023/5/9 | 5 | 6.219 | 0.313 | 3.294 | 0.404 | 1.888 | 0.211 | 7 | 2.306 | 0.283 | 1.321 | 0.148 | | | | | | | | | | | |
| 2023/5/20 | 30 | 29.363 | 0.407 | 11.566 | 0.533 | 2.539 | 0.112 | 23 | 26.602 | 1.227 | 5.839 | 0.257 | | | | | | | | | | | |
| 2023/5/21 | 5 | 71.394 | 0.634 | 25.434 | 0.786 | 2.807 | 0.083 | 0.3 | 0.763 | 0.024 | 0.084 | 0.002 | | | | | | | | | | | |
| 2023/5/25 | 8 | 35.826 | 0.433 | 14.838 | 0.552 | 2.415 | 0.085 | 1.3 | 1.929 | 0.072 | 0.314 | 0.011 | | | | | | | | | | | |

| | | | | | | | | | | | | |
|-----------|-----|--------|-------|--------|-------|-------|-------|------|--------|-------|--------|-------|
| 2023/5/26 | 4.5 | 42.148 | 0.518 | 15.249 | 0.636 | 2.764 | 0.110 | 1.3 | 1.982 | 0.083 | 0.359 | 0.014 |
| 2023/5/27 | 48 | 8.665 | 0.212 | 4.029 | 0.350 | 2.151 | 0.179 | 4 | 1.612 | 0.140 | 0.860 | 0.072 |
| 2023/5/29 | 30 | 12.194 | 0.245 | 5.698 | 0.341 | 2.140 | 0.121 | 18.2 | 10.371 | 0.620 | 3.895 | 0.219 |
| 2023/5/31 | 18 | 9.738 | 0.212 | 5.039 | 0.302 | 1.932 | 0.108 | 25 | 12.599 | 0.755 | 4.831 | 0.270 |
| 2023/6/2 | 48 | 7.123 | 0.231 | 4.145 | 0.355 | 1.718 | 0.136 | 27.7 | 11.482 | 0.984 | 4.760 | 0.378 |
| 2023/6/3 | 60 | 8.352 | 0.244 | 5.559 | 0.417 | 1.502 | 0.104 | 32.5 | 18.066 | 1.354 | 4.883 | 0.337 |
| 2023/6/17 | 15 | 6.881 | 0.204 | 3.651 | 0.285 | 1.885 | 0.136 | 8.7 | 3.176 | 0.248 | 1.640 | 0.118 |
| 2023/6/27 | 5 | 19.734 | 0.385 | 7.998 | 0.310 | 2.467 | 0.083 | 12 | 9.597 | 0.372 | 2.961 | 0.099 |
| 2023/7/2 | 30 | 7.000 | 0.174 | 3.407 | 0.194 | 2.055 | 0.105 | 27 | 9.198 | 0.524 | 5.548 | 0.284 |
| 2023/7/13 | 58 | 8.648 | 0.183 | 5.576 | 0.308 | 1.551 | 0.079 | 99.7 | 55.595 | 3.075 | 15.463 | 0.790 |
| 2023/7/20 | 10 | 21.321 | 0.311 | 10.071 | 0.311 | 2.117 | 0.058 | 3.9 | 3.928 | 0.121 | 0.826 | 0.022 |
| 2023/7/28 | 48 | 4.560 | 0.128 | 2.404 | 0.175 | 1.897 | 0.128 | 16 | 3.846 | 0.280 | 3.035 | 0.204 |
| 2023/7/29 | 11 | 4.369 | 0.131 | 1.991 | 0.161 | 2.195 | 0.165 | 3.4 | 0.677 | 0.055 | 0.746 | 0.056 |
| 2023/8/5 | 28 | 9.670 | 0.190 | 5.179 | 0.255 | 1.867 | 0.084 | 35.1 | 18.179 | 0.894 | 6.554 | 0.296 |
| 2023/8/19 | 35 | 4.000 | 0.163 | 2.315 | 0.342 | 1.728 | 0.245 | 19 | 4.399 | 0.650 | 3.283 | 0.466 |
| 2023/8/26 | 120 | 2.720 | 0.133 | 2.298 | 0.425 | 1.183 | 0.211 | 34.3 | 7.883 | 1.458 | 4.059 | 0.724 |
| 2023/9/19 | 7.5 | 4.519 | 0.167 | 3.608 | 0.435 | 1.253 | 0.144 | 61.9 | 22.334 | 2.690 | 7.753 | 0.889 |
| 2023/9/20 | 5 | 3.952 | 0.167 | 2.504 | 0.316 | 1.578 | 0.188 | 16.8 | 4.206 | 0.531 | 2.651 | 0.315 |
| 2023/9/24 | 20 | 2.241 | 0.102 | 1.622 | 0.222 | 1.382 | 0.179 | 14.1 | 2.287 | 0.314 | 1.949 | 0.252 |
| 2023/10/3 | 80 | 3.006 | 0.114 | 2.804 | 0.257 | 1.072 | 0.089 | 21 | 5.888 | 0.539 | 2.251 | 0.187 |
| 2023/10/5 | 10 | 7.616 | 0.197 | 6.489 | 1.066 | 1.174 | 0.190 | 3.9 | 2.531 | 0.416 | 0.458 | 0.074 |