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Supporting Information for

Observational constraint on the contribution of surface albedo feedback to the amplified Tibetan Plateau surface warming

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**Introduction**

In this Supporting Information we provide additional figures (Figures S1-S2) and tables (Tables S1-S5) that support the results in the main text.



**Figure S1**. The spatial distributions of surface albedo change (∆α) from 1982-1998 to 1999-2015 in winter (DJF) and spring (MAM) for six reanalysis datasets: ERA-Interim (ERAI, a, b), ERA5 (c, d), MERRA (e, f), MERRA-2 (g, h), JRA-55 (i, j) and CRA (k, l) over the TP above 2000m a.s.l.. The black box in (a, b) denotes the middle and eastern TP (27°N~40°N, 82°E~105°E) where surface albedo increases significantly for ERA-Interim.



**Figure S2**. Winter (DJF) and spring (MAM) mean surface albedo (a, c) and snow cover fraction (b, d) anomalies over the middle and eastern TP (27°N~40°N, 82°E~105°E) above 2000 m a.s.l. during 1982-2015. The orange and purple lines in (a, b) denote GLASS and CLARA-A2 satellite surface albedo products respectively, the black lines in (c, d) denote the snow cover fraction derived from the passive microwave remote sensing datasets (Che et al., 2008; Dai et al., 2015; Che et al., 2019), and the pink, green, brown, blue, red, and seagreen lines in (a, b, c, d) denote EAR-Interim (ERAI), ERA5, MERRA, MERRA-2, JRA-55, and CRA respectively. The colored number in the figure is linear trend (units: 1/10a) of each dataset assessed by using the Theil-Sen trend estimation method. The \* marker indicates a linear trend is significant at the 95% confidence level with p ≤ 0.05 by using Mann-Kendall test.

**Table S1**. List of 28 CMIP6 climate models used in this study.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No | Model | Institution | Resolution lat×lon  over TP (degree) | Key references |
| 1 | ACCESS-CM2 | CSIRO-ARCCSS | 1.25°×1.875° | Dix et al. (2019) |
| 2 | ACCESS-ESM1-5 | CSIRO | 1.25°×1.875° | Ziehn et al. (2019) |
| 3 | BCC-ESM1 | BCC | 2.79°×2.81° | Zhang et al. (2019) |
| 4 | CanESM5 | CCCma | 2.79°×2.81° | Swart et al. (2019) |
| 5 | CESM2 | NCAR | 0.94°×1.25° | Danabasoglu (2019) |
| 6 | CESM2-FV2 | NCAR | 1.895°×2.5° | Danabasoglu (2020) |
| 7 | CESM2-WACCM | NCAR | 0.94°×1.25° | Danabasoglu (2019) |
| 8 | CESM2-WACCM-FV2 | NCAR | 1.895°×2.5° | Danabasoglu (2020) |
| 9 | CIESM | THU | 0.94°×1.25° | Huang (2020) |
| 10 | CMCC-CM2-HR4 | CMCC | 0.94°×1.25° | Scoccimarro et al. (2021) |
| 11 | CMCC-CM2-SR5 | CMCC | 0.94°×1.25° | Lovato and Peano (2020) |
| 12 | EC-Earth3-AerChem | EC-Earth-Consortium | 0.702°×0.703° | EC-Earth Consortium (2020) |
| 13 | EC-Earth3-CC | EC-Earth-Consortium | 0.702°×0.703° | EC-Earth Consortium (2021) |
| 14 | FGOALS-f3-L | CAS | 1.0°×1.25° | Yu (2018) |
| 15 | FGOALS-g3 | CAS | 2.025°×2.0° | Li (2019) |
| 16 | IITM-ESM | CCCR-IITM | 1.905°×1.875° | Raghavan and Panickal (2020) |
| 17 | INM-CM4-8 | INM | 1.5°×2.0° | Volodin et al. (2019) |
| 18 | INM-CM5-0 | INM | 1.5°×2.0° | Volodin et al. (2019) |
| 19 | IPSL-CM6A-LR | IPSL | 1.268°×2.5° | Boucher et al. (2018) |
| 20 | KACE-1-0-G | NIMS-KMA | 1.25°×1.875° | Byun et al. (2019) |
| 21 | MIROC6 | MIROC | 1.401°×1.406° | Tatebe et al. (2018) |
| 22 | MPI-ESM-1-2-HAM | HAMMOZ-Consortium | 1.865°×1.875° | Neubauer et al. (2019) |
| 23 | MPI-ESM1-2-HR | MPI-M | 0.935°×0.938° | Jungclaus et al. (2019) |
| 24 | MPI-ESM1-2-LR | MPI-M | 1.865°×1.875° | Wieners et al. (2019) |
| 25 | MRI-ESM2-0 | MRI | 1.121°×1.125° | Yukimoto et al. (2019) |
| 26 | NESM3 | NUIST | 1.865°×1.875° | Cao and Wang (2019) |
| 27 | NorCPM1 | NCC | 1.895°×2.5° | Bethke et al. (2019) |
| 28 | SAM0-UNICON | SNU | 0.94°×1.25° | Park and Shin (2019) |

The horizontal resolution of each model is the average resolution over the TP region (27o-40oN, 75o-105oE).

**Table S2**. Magnitude of the items composing ΔTSAF averaged over the 75 meteorological stations during winter (DJF) and spring (MAM).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Season** | **Dataset** |  |  |  |  | **ΔTSAF** |  |  |
| **Winter** | ERAI | -0.25 | 0.020 | 174.01 | 174.93 | -0.77 | 0.21 | 0.52 |
| ERA5 | -0.26 | -0.017 | 178.19 | 178.45 | 0.85 | 0.21 | 0.58 |
| MERRA | -0.25 | -0.014 | 179.12 | 180.33 | 0.71 | 0.21 | 0.56 |
| MERRA-2 | -0.24 | -0.001 | 175.11 | 176.92 | 0.07 | 0.20 | 0.52 |
| JRA-55 | -0.25 | -0.028 | 188.23 | 187.77 | 1.38 | 0.22 | 0.57 |
| CRA | -0.25 | -0.023 | 168.51 | 169.86 | 1.11 | 0.20 | 0.52 |
| OBS |  | (-0.012\*, -0.004) | 159.46 | 159.14 |  |  |  |
| CV | -0.02 | -1.64 | 0.04 | 0.03 | 1.41 | 0.04 | 0.05 |
| **Spring** | ERAI | -0.22 | 0.014 | 278.05 | 277.74 | -0.84 | 0.35 | 0.64 |
| ERA5 | -0.22 | -0.028 | 282.54 | 280.47 | 1.73 | 0.36 | 0.68 |
| MERRA | -0.21 | -0.003 | 295.91 | 294.12 | 0.19 | 0.33 | 0.66 |
| MERRA-2 | -0.21 | 0.001 | 284.87 | 281.05 | -0.05 | 0.31 | 0.62 |
| JRA-55 | -0.22 | -0.013 | 294.77 | 292.62 | 0.83 | 0.34 | 0.66 |
| CRA | -0.22 | -0.023 | 270.07 | 269.52 | 1.42 | 0.33 | 0.63 |
| OBS |  | (-0.010\*, -0.005) | 253.99 | 252.17 |  |  |  |
| CV | -0.02 | -1.79 | 0.03 | 0.03 | 1.76 | 0.06 | 0.04 |

Each item in the table is averaged over the 75 meteorological stations. denotes sensitivity parameter, △α denotes the change of surface albedo (α) between two climatic periods, (units of W/m2) denotes the average of for the first climate period, (units of W/m2) denotes the change of between the two climate periods. The observational information ("OBS") for α and is estimated from surface albedo of CLARA-A2 and GLASS, and SunDu-derived . The calculation of ΔTSAF (units of K) is based on TS, α and of each dataset according to Eq. (2). The calculation of and (units of K) isbased on TS, of each reanalysis dataset and surface albedo of CLARA-A2 and GLASS dataset. The CV denotes coefficient of variation of the six reanalysis datasets, which is defined as the standard derivation (σ) divided by the mean (µ): CV = σ/µ. The \* marker indicates the change of surface albedo between two climate periods is significant at the 95% level with p ≤ 0.05 using the Student's t-test.

**Table S3**. Magnitude of the items composing ΔTSAF averaged over the entire TP higher than 2000 m a.s.l. during winter (DJF) and spring (MAM).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Season** | **Dataset** |  |  |  |  |  |  |  |
| **Winter** | ERAI | -0.25 | 0.015 | 170.37 | 171.63 | -0.62 | 0.20 | 0.44 |
| ERA5 | -0.26 | -0.011 | 172.24 | 172.93 | 0.53 | 0.21 | 0.48 |
| MERRA | -0.25 | -0.016\* | 175.32 | 176.74 | 0.80 | 0.23 | 0.47 |
| MERRA-2 | -0.24 | 0.001 | 169.22 | 171.98 | -0.04 | 0.20 | 0.43 |
| JRA-55 | -0.25 | -0.023\* | 183.29 | 183.40 | 1.18 | 0.23 | 0.47 |
| CRA | -0.25 | -0.016 | 166.19 | 167.59 | 0.78 | 0.21 | 0.44 |
| OBS |  | (-0.011\*, -0.005) |  |  |  |  |  |
| CV | -0.02 | -1.65 | 0.03 | 0.03 | 1.50 | 0.07 | 0.04 |
| **Spring** | ERAI | -0.22 | 0.004 | 285.29 | 286.43 | -0.23 | 0.34 | 0.83 |
| ERA5 | -0.23 | -0.019\* | 287.60 | 287.43 | 1.25 | 0.35 | 0.88 |
| MERRA | -0.22 | -0.007\* | 299.17 | 298.50 | 0.49 | 0.33 | 0.86 |
| MERRA-2 | -0.21 | 0.000 | 284.66 | 284.02 | -0.03 | 0.30 | 0.79 |
| JRA-55 | -0.22 | -0.012\* | 300.09 | 298.85 | 0.81 | 0.33 | 0.87 |
| CRA | -0.22 | -0.014 | 274.48 | 275.60 | 0.83 | 0.32 | 0.83 |
| OBS |  | (-0.014\*, -0.005) |  |  |  |  |  |
| CV | -0.02 | -1.13 | 0.03 | 0.03 | 1.08 | 0.05 | 0.04 |

Each item is calculated as for Table 2 but averaged over the entire TP higher than 2000 m a.s.l.

**Table S4**. The estimated ΔTSAF (units of K) for the entire TP in winter (DJF) and spring (MAM) by using different methods for each reanalysis and observational datasets.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Dataset |  |  |  |  |
| Winter | ERAI | -0.62 | -0.66 | -0.59 | -0.53 |
| ERA5 | 0.53 | 0.56 | 0.57 | 0.52 |
| MERRA | 0.80 | 0.80 | 0.81 | 0.73 |
| MERRA-2 | -0.04 | 0.00 | 0.04 | 0.04 |
| JRA-55 | 1.18 | 1.13 | 1.13 | 1.01 |
| CRA | 0.78 | 0.79 | 0.80 | 0.72 |
| CLARA-A2 |  | 0.26 | 0.29 | 0.26 |
| GLASS |  | 0.54 | 0.55 | 0.50 |
| Spring | ERAI | -0.23 | -0.25 | -0.25 | -0.22 |
| ERA5 | 1.25 | 1.23 | 1.18 | 1.06 |
| MERRA | 0.49 | 0.46 | 0.43 | 0.39 |
| MERRA-2 | -0.03 | -0.00 | -0.02 | -0.01 |
| JRA-55 | 0.81 | 0.80 | 0.76 | 0.69 |
| CRA | 0.83 | 0.88 | 0.85 | 0.76 |
| CLARA-A2 |  | 0.31 | 0.29 | 0.27 |
| GLASS |  | 0.90 | 0.86 | 0.77 |

is estimated directly by using Eq. (2) for each reanalysis dataset. , and are estimated by using different linearly relationships between ∆𝛼 and ∆TSAF in conjunction with the entire TP averaged surface albedo change from each dataset. is estimated with the linear regression between the entire TP averaged ∆𝛼 and ∆TSAF from six reanalysis datasets. is estimated with the linear regression between the 75-station averaged ∆𝛼 and ∆TSAF from the six reanalysis datasets. is estimated with the linear regression between the 75-station averaged ∆𝛼 and ∆TSAF from six reanalysis datasets but using the SunDu-derived .

**Table S5**. The range of , - and their sum () (units of K) averaged over the entire TP in winter (DJF) and spring (MAM) from six reanalysis datasets and 28 CMIP6 models.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Reanalysis datasets | | | CMIP6 models | | |
| Season |  |  |  |  |  |  |
| Winter | [-0.63, 1.18] | [-0.56, 0.49] | [-0.22, 0.61] | [-0.55, 1.43] | [-0.89, 0.43] | [-0.60, 0.78] |
| Spring | [-0.25, 1.25] | [-0.74, 0.27] | [ 0.02, 0.51] | [-0.15, 1.89] | [-0.87. 0.32] | [-0.40, 1.04] |