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Supplement of

Unraveling the discrepancies between Eulerian and Lagrangian moisture tracking models in monsoon- and westerly-dominated basins of the Tibetan Plateau

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Sect. 1:

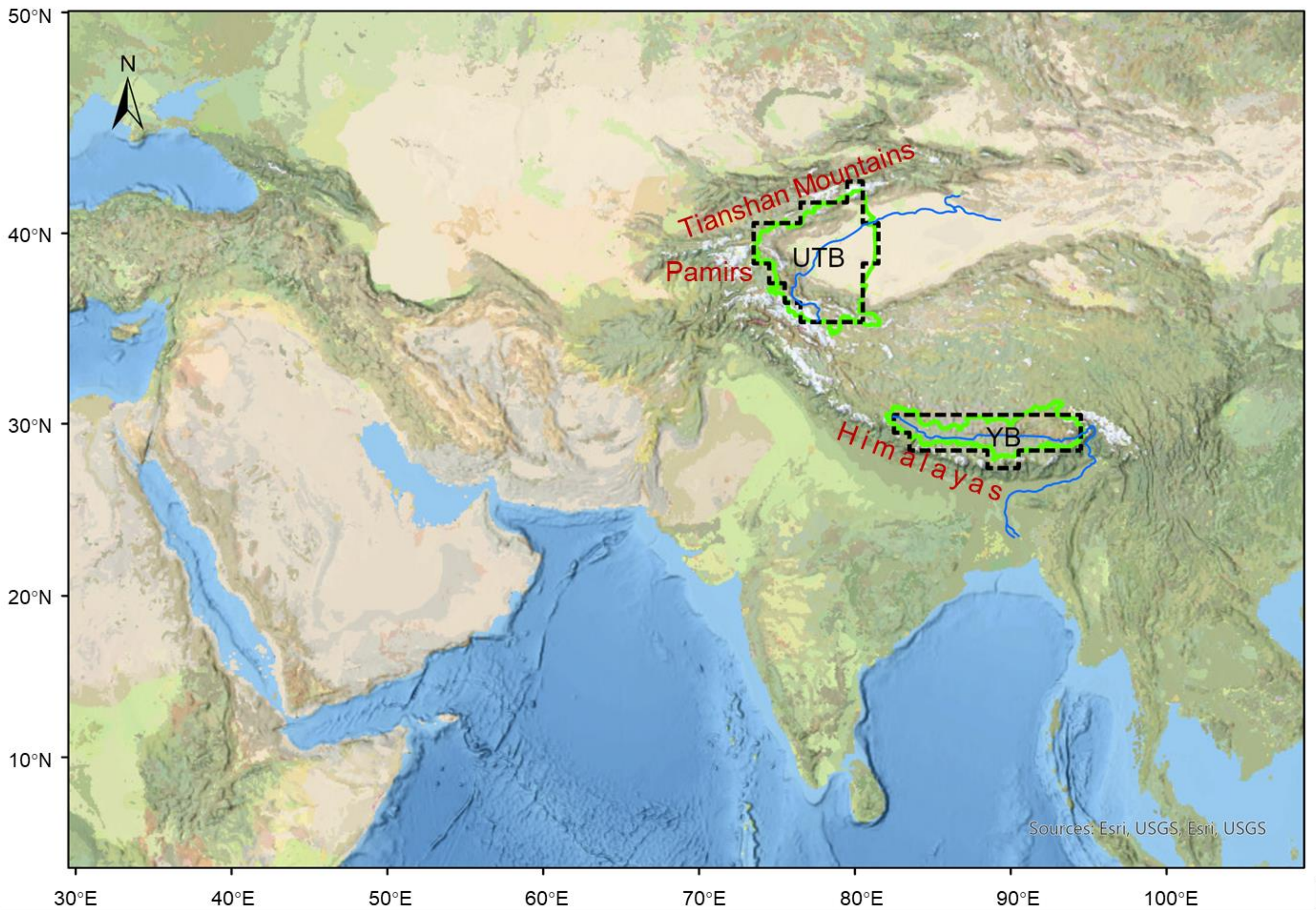

Figure S1. Topography and location of the Yarlung Zangbo River Basin (YB) and the upper Tarim River Basin (UTB). Solid cyan lines represent the actual watershed boundaries. Dotted black lines depict the computational boundaries. Blue lines represent the rivers. Generally, the monsoon influences the YB after traveling across the Himalayas, whereas the westerlies impact the UTB after crossing the Pamirs and Tianshan Mountains.

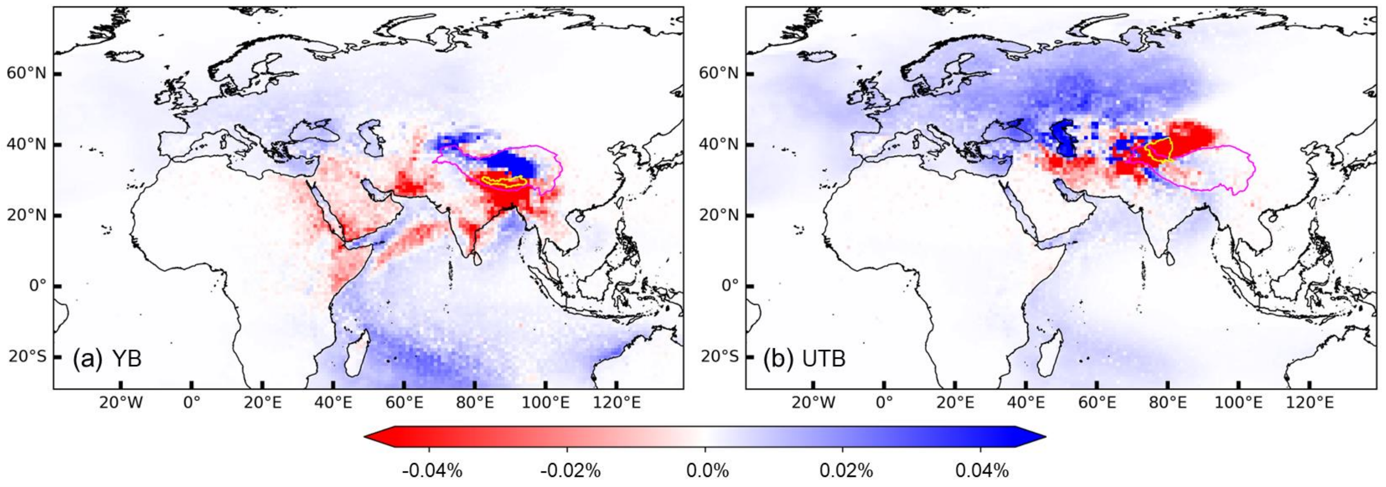

Figure S2. Relative differences in moisture contributions between WAM2layers and FLEXPART-WaterSip (WAM2layers minus FLEXPART-WaterSip) for the (a) YB and (b) UTB.

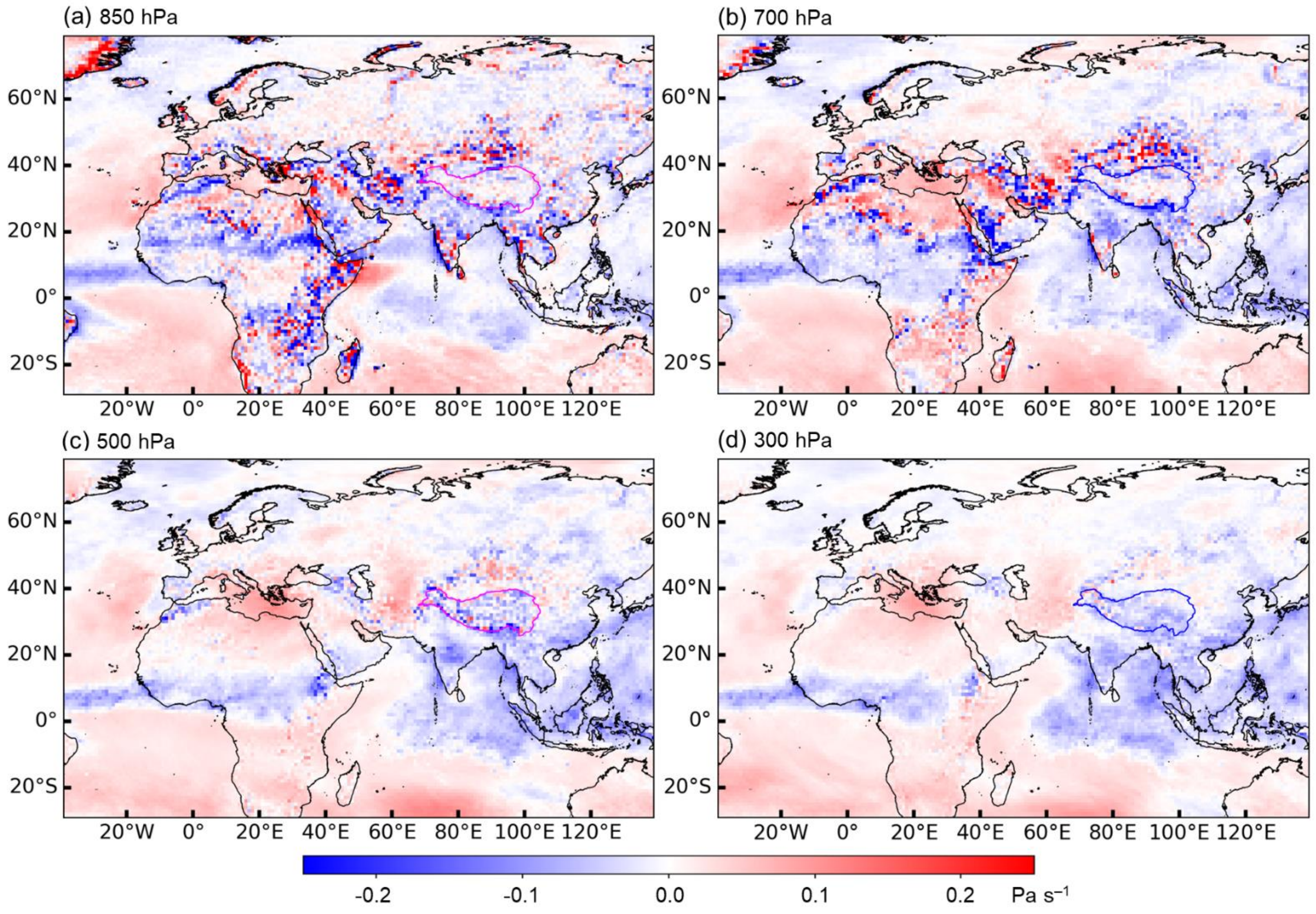

Figure S3. Vertical velocities (Pa s^{-1}) at (a) 850 hPa, (b) 700 hPa, (c) 500 hPa, and (d) 300 hPa across the entire study domain during June–July 2022. Note the negative values indicate upward motion (ascent).

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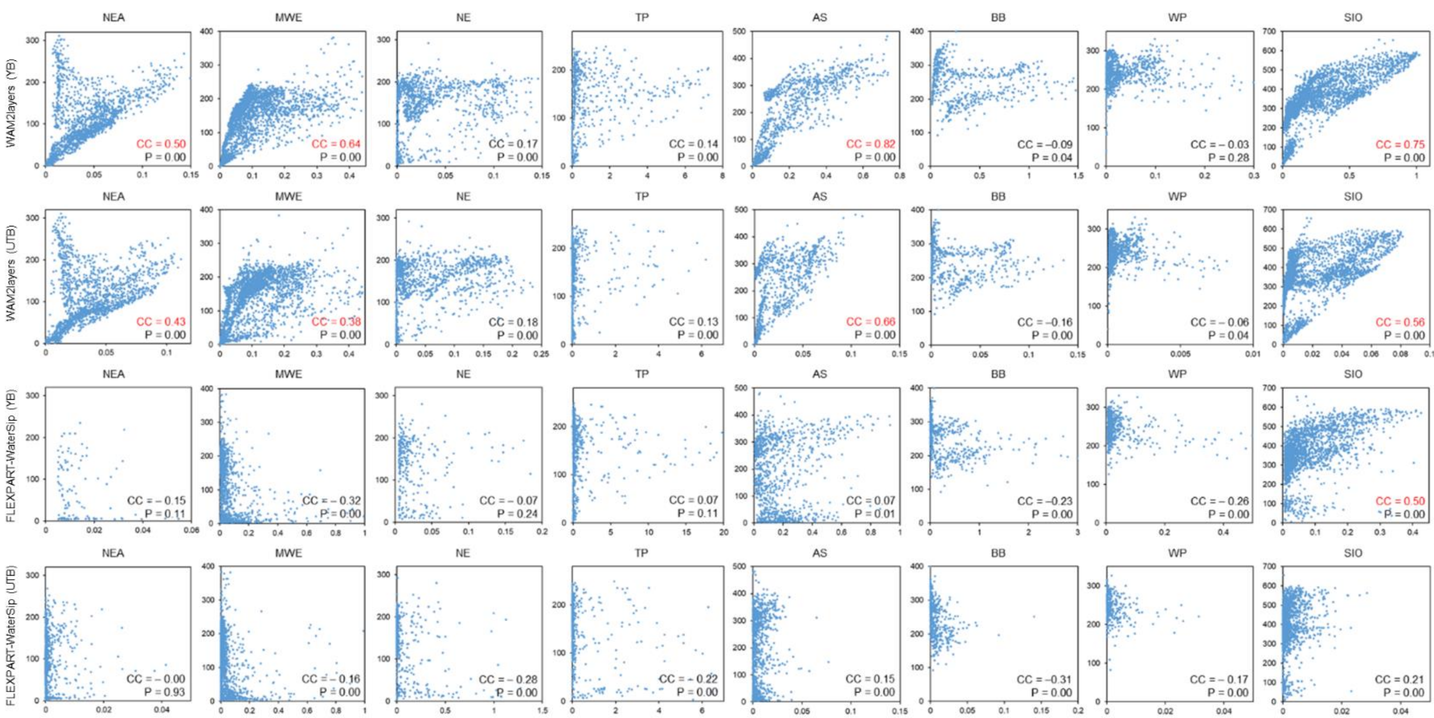

Figure S4. Scatter plots between actual evaporation (vertical axis; mm) and simulated moisture contributions (horizontal axis; mm) for grid cells in the eight selected source regions. The first and second rows are results from WAM2layers model, while the third and fourth rows are results from FLEXPART-WaterSip models. In each subplot, "CC" is the correlation coefficient of all the cells and "P" is the p-value under two-tail t-test. "CC" values larger than 0.3 are marked in red.

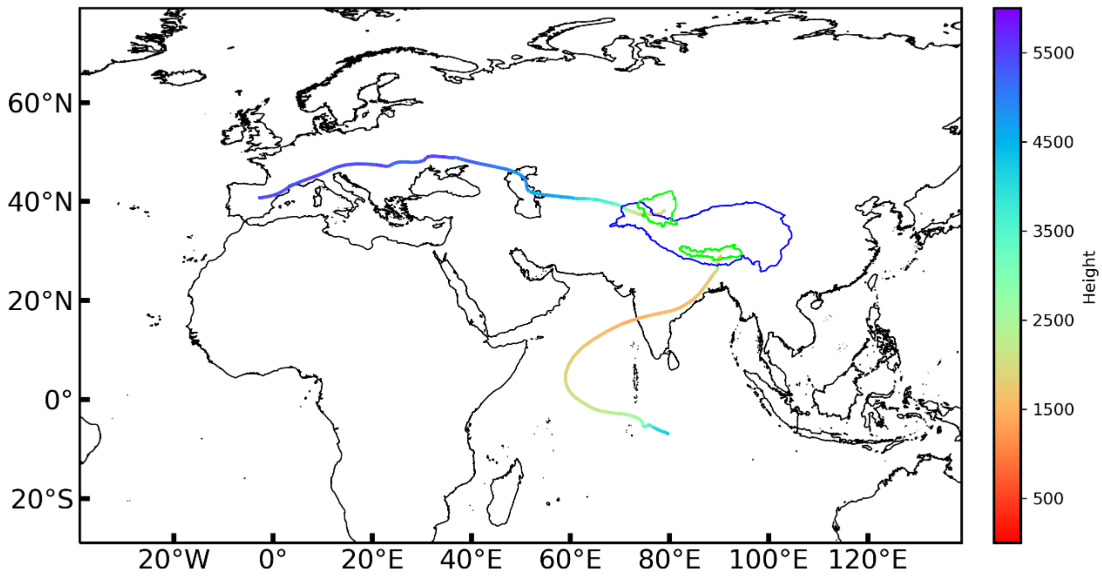

Figure S5. Two selected moisture transport trajectories originating from the SIO and NEA that result in precipitation in the YB and UTB, respectively. Colors represent the heights of the trajectories (in m).

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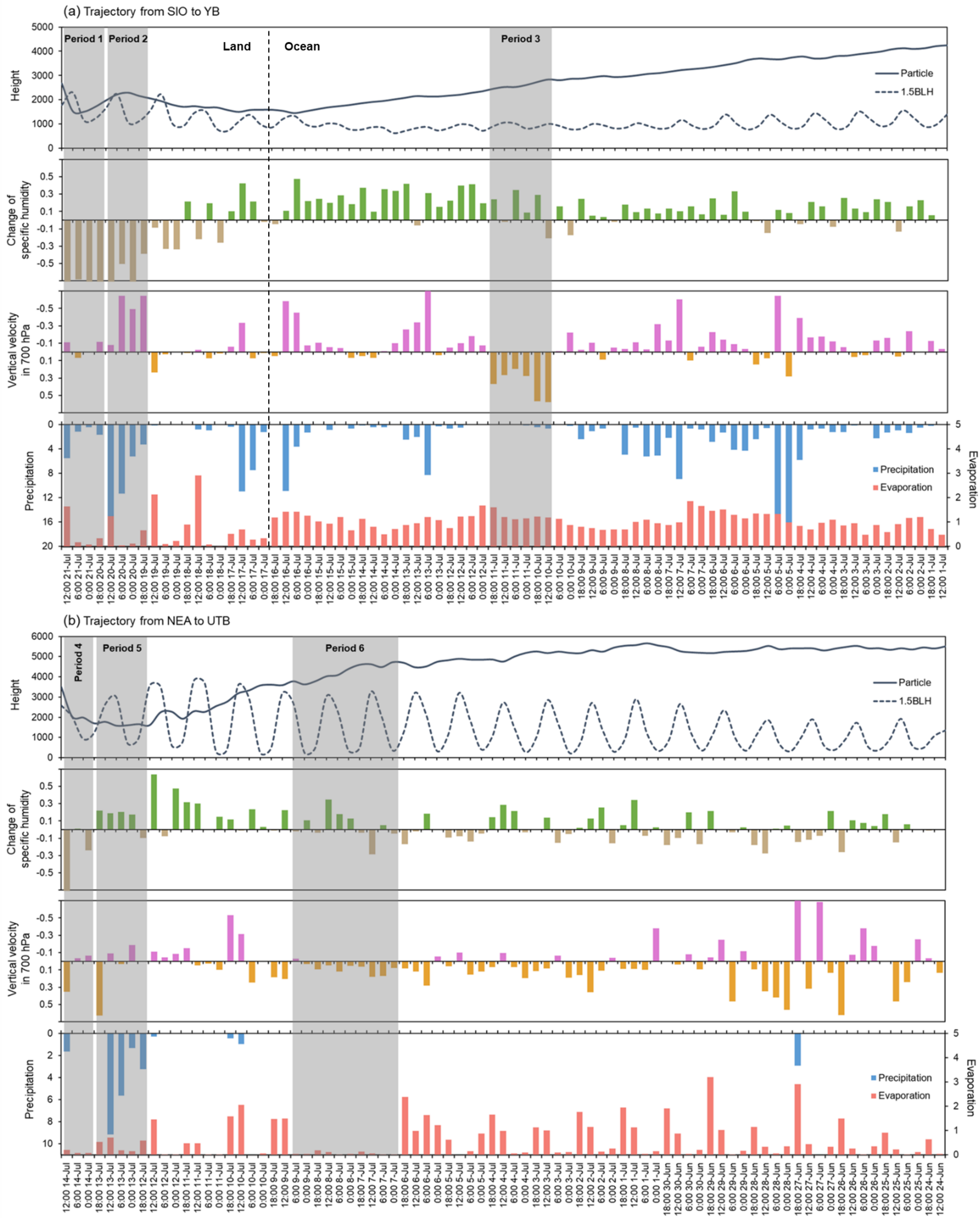
(a) Trajectory from SIO to YB
Period 1
Period 2
Land
Ocean
Period 3
Height
Particle
1.5BLH
Change of specific humidity
Vertical velocity in 700 hPa
Precipitation
Evaporation
(b) Trajectory from NEA to UTB
Period 4
Period 5
Period 6
Height
Particle
1.5BLH
Change of specific humidity
Vertical velocity in 700 hPa
Precipitation
Evaporation

Figure S6. Time series of particle height (m), 1.5 BLH (m), specific humidity change (g kg^{-1}), vertical velocity at 700 hPa (Pa s^{-1}), precipitation (mm), and evaporation (mm) at 6-hourly intervals for the two selected trajectories in Fig. S5: (a) a trajectory from the SIO to the YB between 12:00 on 21-July (arrival time) and 12:00 on 1-July; and (b) a trajectory from the NEA to the UTB between 12:00 on 14-July (arrival time) and 12:00 on 24-June. Note that particle height, 1.5 BLH, and specific humidity change are from FLEXPART-WaterSip simulation, while vertical velocity at 700 hPa, precipitation, and evaporation are from ERA5. The time series are presented in reverse chronological order. This Figure illustrates the acquisition of moisture in the source regions and subsequent loss of moisture as traveling toward the target regions (specific humidity changes), pronounced updrafts during monsoonal moisture transport (vertical velocity in Fig. S6a), limited convective activities over the hinterland Eurasia (vertical velocity in Fig. S6b), strong evaporation and precipitation in the ISM-dominated regions (precipitation and evaporation in Fig. S6a), and weak precipitation but strong diurnal evaporation in the westerlies-dominated regions (precipitation and evaporation in Fig. S6b). Six periods (shaded areas in Fig. S6) are selected for comparison. Compared to Period 1, Period 2 shows less moisture loss but stronger convective activity and enhanced precipitation. During Period 3, intense atmospheric subsidence is observed, suggesting that evaporation may struggle to transport to the upper atmosphere. Nonetheless, moisture uptake during this period does not substantially decrease. Compared to Period 4, Period 5 is marked by intense precipitation yet continues to experience moisture uptake. Period 6 sees minimal evaporation and relatively weak atmospheric subsidence, but moisture uptake remains comparable to other periods in Fig. S6b. It should be noted that the comparisons here may involve considerable uncertainties and could be influenced by various meteorological factors.

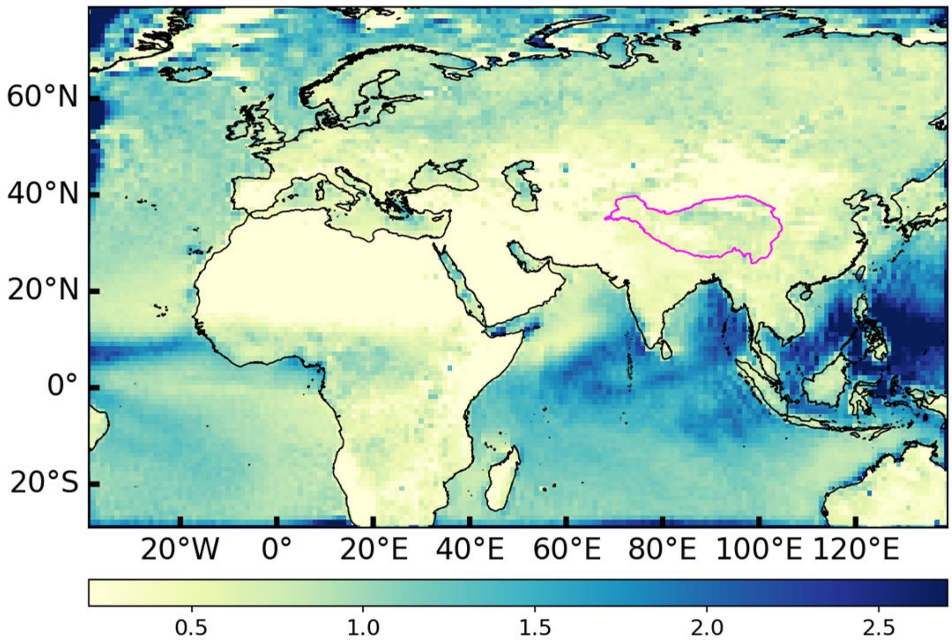

Figure S7. Spatial distribution of correction factors over the entire tracking domain.

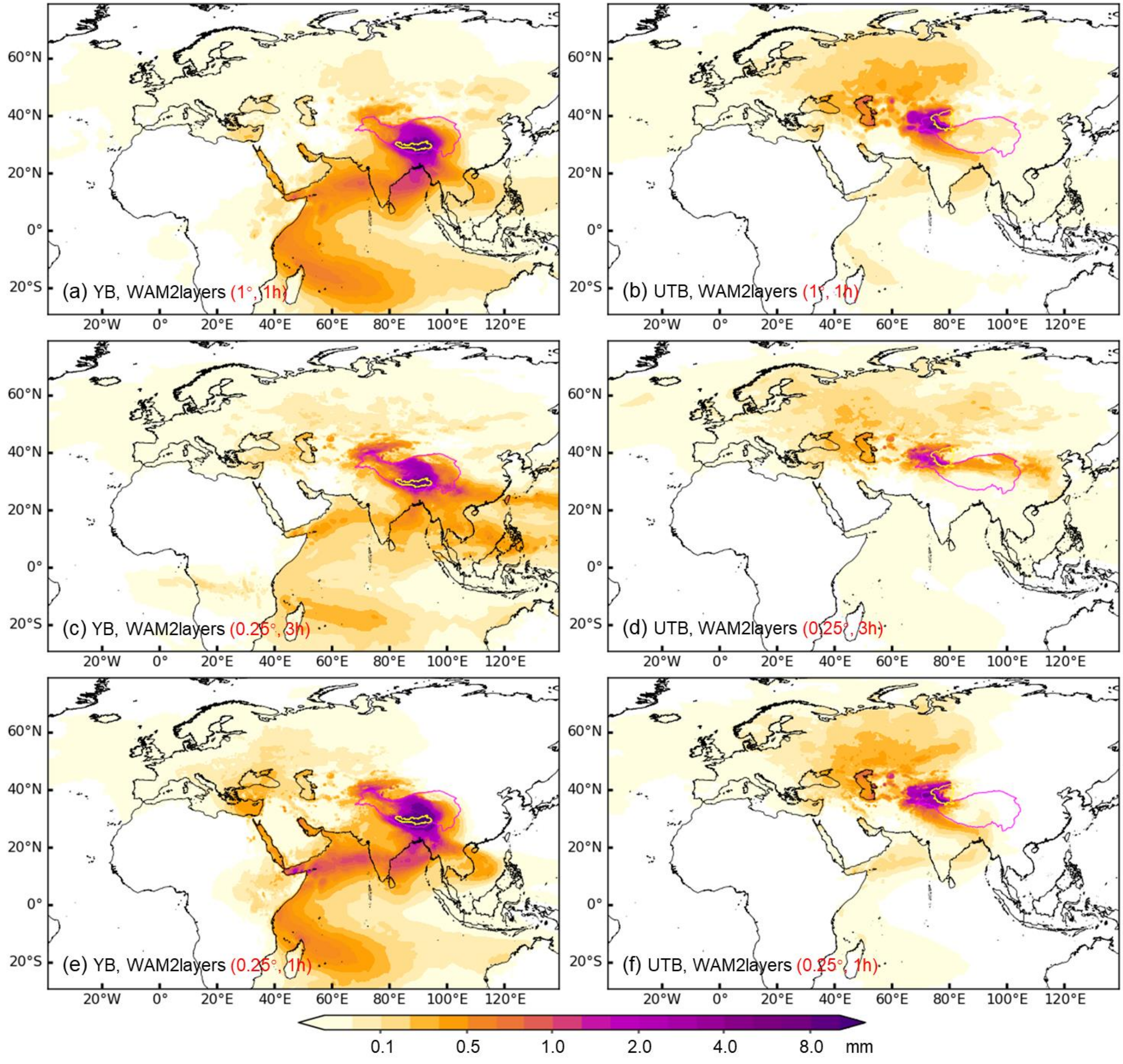

Figure S8. Spatial distributions of moisture contributions (equivalent water height over source regions; mm) to precipitation in July 2022 in the (a, c, and e) YB and (b, d, and f) UTB simulated by WAM2layers model with different model resolution configurations as in Experiment 1: (a and b) 1°×1° at hourly resolution, (c and d) 0.25°×0.25° at 3-hourly resolution, and (e and f) 0.25°×0.25° at hourly resolution. Purple lines represent the TP boundary and yellow lines represent the boundaries of the two representative basins.

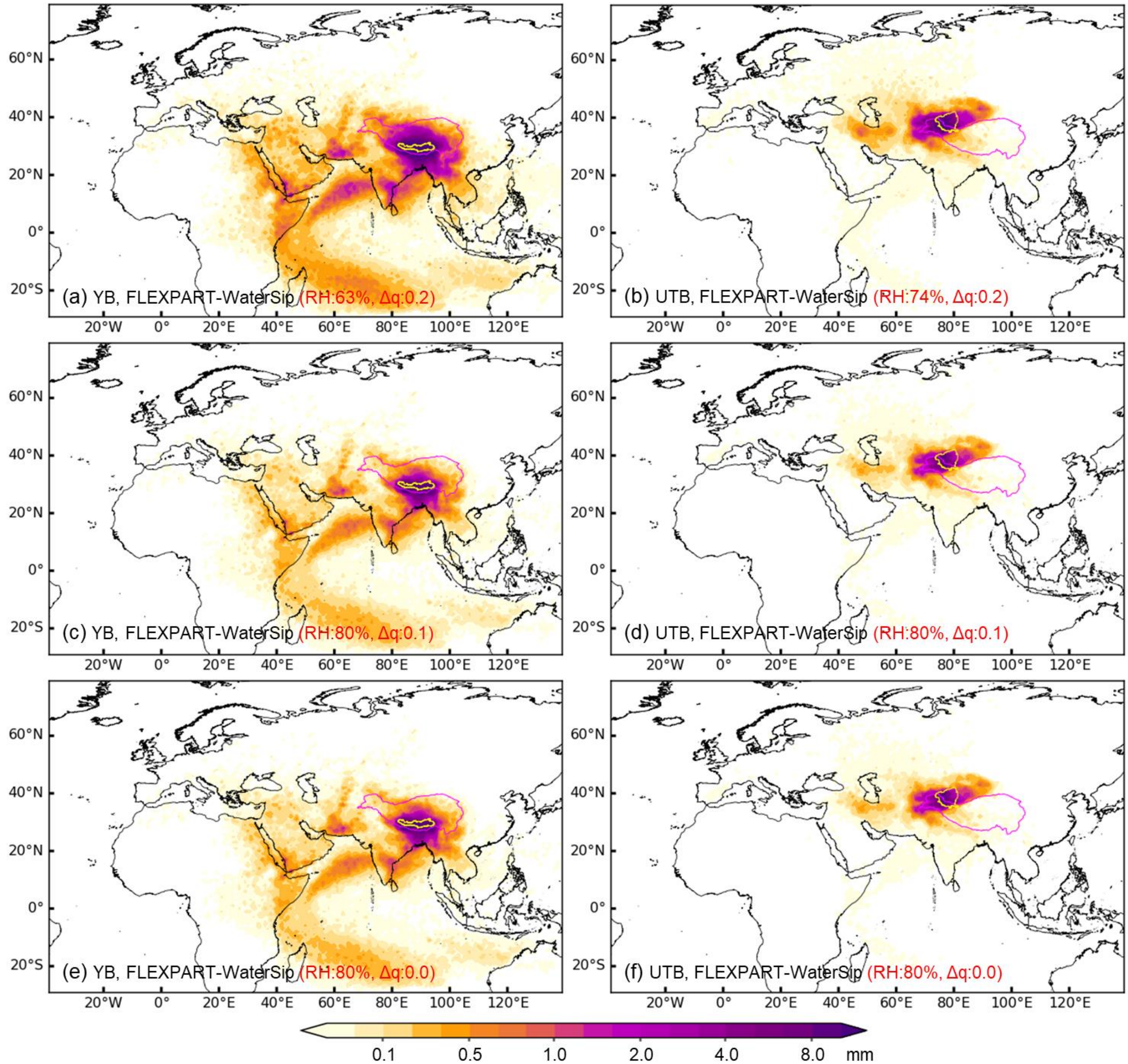

Figure S9. Spatial distributions of moisture contributions (equivalent water height over source regions; mm) to precipitation in July 2022 in the (a, c, and e) YB and (b, d, and f) UTB simulated by FLEXPART-WaterSip model with different moisture source diagnosis thresholds, i.e., relative humidity threshold (RH) and specific humidity change threshold (Δq), as in

Experiment 2: (a) RH = 63% and $\Delta q = 0.2$ g kg^{-1}, (b) RH = 74% and $\Delta q = 0.2$ g kg^{-1}, (c and d) RH = 80% and $\Delta q = 0.1$ g kg^{-1}, and (e and f) RH = 80% and $\Delta q = 0$ g kg^{-1}. Purple lines represent the TP boundary and yellow lines represent the boundaries of the two representative basins.

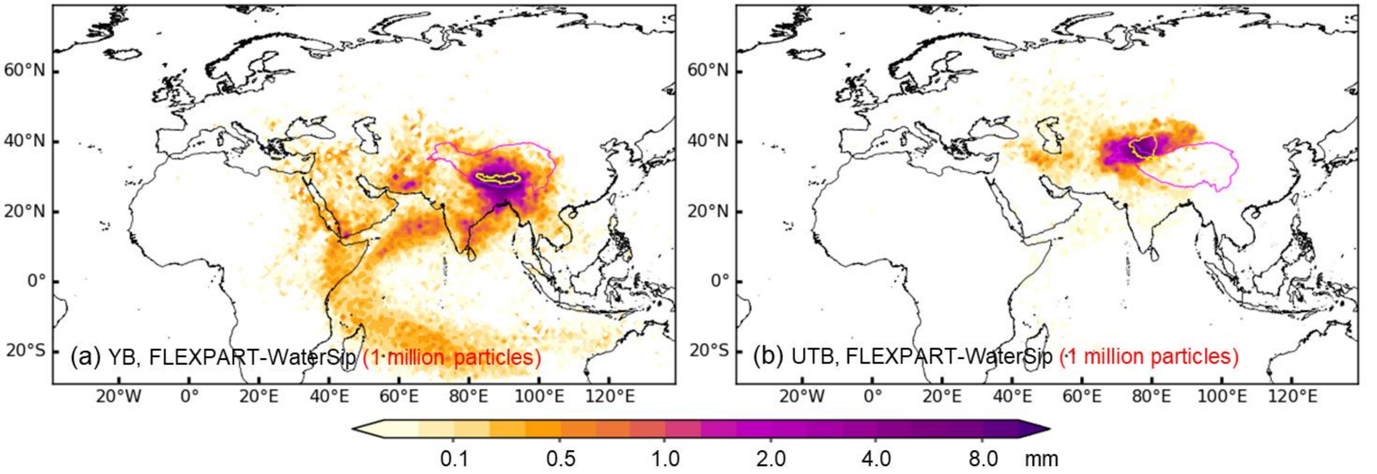

Figure S10. Spatial distributions of moisture contributions (equivalent water height over source regions; mm) to precipitation in July 2022 in the (a) YB and (b) UTB simulated by FLEXPART-WaterSip model with 1 million particles released as in Experiment 3. Purple lines represent the TP boundary and yellow lines represent the boundaries of the two representative basins.

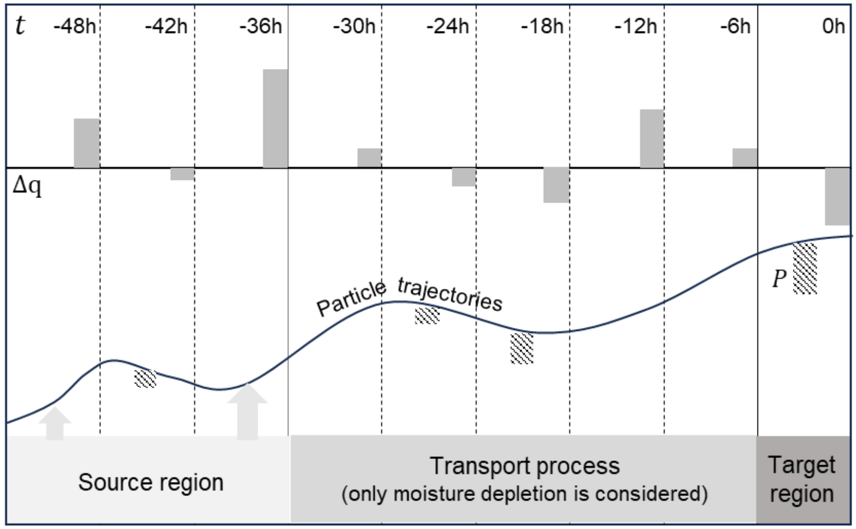

Figure S11. Mechanism of the “areal source-receptor attribution” method (cf. Fig. 1b for the WaterSip method).

Sect. 2:

 # Configurations of WAM2layer model

```
# General
log_level: info
preprocessed_data_folder: ..\preprocessed_data
output_folder: ..\output_file
# Preprocessing
filename_template: ..\{year}\{month:02}\ERA5_{year}-{month:02d}-{day:02d}{levtype}_{variable}.nc
preprocess_start_date: "2022-06-01T00:00"
preprocess_end_date: "2022-07-31T21:00"
level_type: model_levels
levels: [20,40,60,80,90,95,100,105,110,115,120,123,125,128,130,131,132,133,134,135,136,137]
# Tracking
tracking_direction: backward
tracking_domain: null
tracking_start_date: "2022-06-01T00:00"
tracking_end_date: "2022-07-31T21:00"
# Tagging
tagging_region: ..\mask.nc
tagging_start_date: "2022-07-01T00:00"
tagging_end_date: "2022-07-31T21:00"
input_frequency: "3h"
timestep: 900
output_frequency: "1d"
restart: False
periodic_boundary: false
kvf: 3
```

 # Configurations of FLEXPART model

```
&COMMAND
 LDIRECT= 1, ! Simulation direction in time   ; 1 (forward) or -1 (backward)
 IBDATE= 20220601, ! Start date of the simulation   ; YYYYMMDD: YYYY=year, MM=month, DD=day
 IBTIME= 000000, ! Start time of the simulation   ; HHMISS: HH=hours, MI=min, SS=sec; UTC
 IEDATE= 20220731, ! End date of the simulation     ; same format as IBDATE
 IETIME= 210000, ! End  time of the simulation    ; same format as IBTIME
 LOUTSTEP= 21600, ! Interval of model output; average concentrations calculated every LOUTSTEP (s)
 LOUTAVER= 21600, ! Interval of output averaging (s)
 LOUTSAMPLE= 900, ! Interval of output sampling  (s), higher stat. accuracy with shorter intervals
 ITSPLIT= 999999999, ! Interval of particle splitting (s)
 LSYNCTIME= 900, ! All processes are synchronized to this time interval (s)
 CTL= -5.0000000, ! CTL>1, ABL time step = (Lagrangian timescale (TL))/CTL, uses LSYNCTIME if CTL<0
 IFINE= 4, ! Reduction for time step in vertical transport, used only if CTL>1
 IOUT= 9, ! Output type: [1]mass 2]pptv 3]1&2 4]plume 5]1&4, +8 for NetCDF output
 IPOUT= 1, ! Particle position output: 0]no 1]every output 2]only at end 3]time averaged
 LSUBGRID= 1, ! Increase of ABL heights due to sub-grid scale orographic variations;[0]off 1]on
 LCONVECTION= 1, ! Switch for convection parameterization;0]off [1]on
 LAGESPECTRA= 0, ! Switch for calculation of age spectra (needs AGECLASSES);[0]off 1]on
 IPIN= 0, ! Warm start from particle dump (needs previous partposit_end file); [0]no 1]yes
 IOUTPUTFOREACHRELEASE= 0, ! Separate output fields for each location in the RELEASE file; [0]no 1]yes
 IFLUX= 0, ! Output of mass fluxes through output grid box boundaries
 MDOMAINFILL= 1, ! Switch for domain-filling, if limited-area particles generated at boundary
 IND_SOURCE= 1, ! Unit to be used at the source   ;  [1]mass 2]mass mixing ratio
 IND_RECEPTOR= 1, ! Unit to be used at the receptor; [1]mass 2]mass mixing ratio 3]wet depo. 4]dry depo.
 MQUASILAG= 1, ! Quasi-Lagrangian mode to track individual numbered particles
```

```
 NESTED_OUTPUT= 0, ! Output also for a nested domain
 LINIT_COND= 0, ! Output sensitivity to initial conditions (bkw mode only) [0]off 1]conc 2]mmr
 SURF_ONLY= 0, ! Output only for the lowest model layer, used w/ LINIT_COND=1 or 2
 CBLFLAG= 0, ! Skewed, not Gaussian turbulence in the convective ABL, need large CTL and IFINE
 OHFIELDS_PATH= "../flexin", ! Default path for OH file

&OUTGRID
 OUTLON0= -40.00,
 OUTLAT0= -30.00,
 NUMXGRID= 181,
 NUMYGRID= 111,
 DXOUT= 1.00,
 DYOUT= 1.00,
 OUTHEIGHTS= 1500.0, 5500.0, 9000.0

&RELEASES_CTRL
 NSPEC= 1, ! Total number of species
 SPECNUM_REL= 24, ! Species numbers in directory SPECIES
 /
&RELEASE ! For each release
 IDATE1 = 20220601, ! Release start date, YYYYMMDD: YYYY=year, MM=month, DD=day
 ITIME1 = 000000, ! Release start time in UTC HHMISS: HH hours, MI=minutes, SS=seconds
 IDATE2 = 20220731, ! Release end date, same as IDATE1
 ITIME2 = 210000, ! Release end time, same as ITIME1
 LON1 = -40.000, ! Left longitude of release box -180 < LON1 <180
 LON2 = 140.000, ! Right longitude of release box, same as LON1
 LAT1 = -30.000, ! Lower latitude of release box, -90 < LAT1 < 90
 LAT2 = 80.000, ! Upper latitude of release box same format as LAT1
 Z1 = 0.000, ! Lower height of release box meters/hPa above reference level
 Z2 = 20000.000, ! Upper height of release box meters/hPa above reference level
 ZKIND = 1, ! Reference level 1=above ground, 2=above sea level, 3 for pressure in hPa
 MASS = 1, ! Total mass emitted, only relevant for fwd simulations
 PARTS = 5000000, ! Total number of particles to be released
 COMMENT = "domain-filling", ! Comment, written in the outputfile
```