S1 Appendix for
Megacity precipitationsheds reveal tele-connected water security challenges

1. Moisture recycling results for 25 megacities

The results of our analysis for the megacities not featured in the main manuscript are presented here. For each of the megacities there are four components:

a) Core precipitationshed (as seen in Fig 3 in manuscript)

b) Analysis of moisture recycling exposure (used in vulnerability analysis), with references

c) Monthly precipitation & terrestrial moisture recycling ratios (as seen in Fig 4 in manuscript)

d) Comparison between dry and wet year precipitationsheds (as seen in Fig 5 in manuscript)

Beijing, China

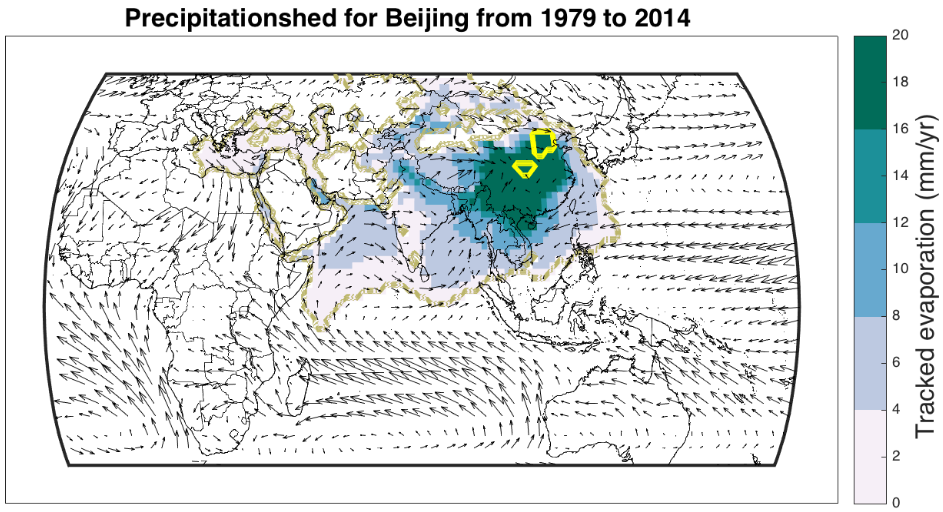

Figure S1: Beijing precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Beijing is one of the most water scarce countries in the world. Limited surface water, and decreasing trends in precipitation and corresponding runoff has led to unsustainable groundwater extraction being used to meet around two thirds of municipal water demand. Surface reservoirs operate at well below design capacity due to decreasing inflow, while pollution has rendered some historically-used reservoirs unsafe. To complement local supply, additional water is transported via the South North Water Transfer project, from the Han River, to the south. The fact that the groundwater aquifer ultimately relies on recharge, that the surface reservoirs are operating below capacity, means that there is little margin for error in water management yet some buffer between runoff and aquifer recharge. We suggest that Beijing's water security is moderately exposed to moisture recycling dynamics.

References

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3. Beijing's Water Crisis 1949 - 2008 Olympics. Probe International Beijing Group. June 2008.

Beijing, China (*continued*)

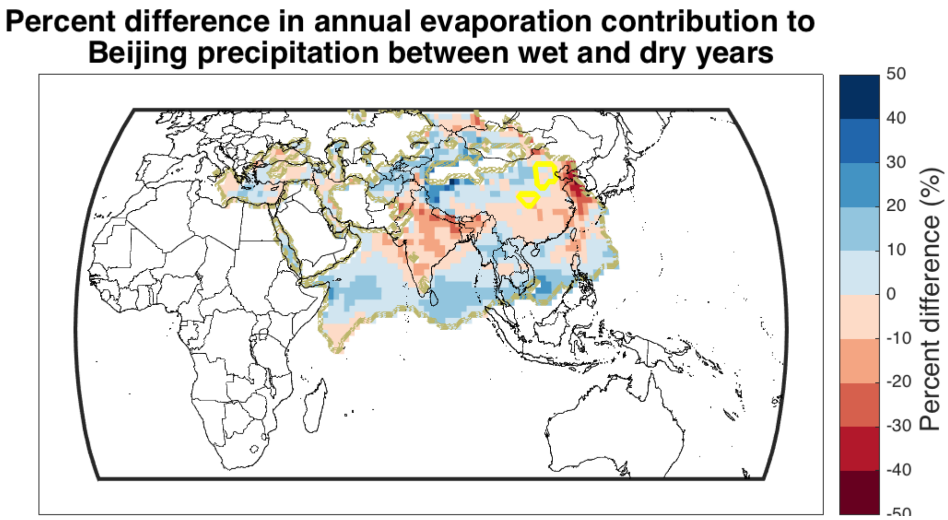

Figure S2: Percent difference in evaporation contribution between driest and wettest years.

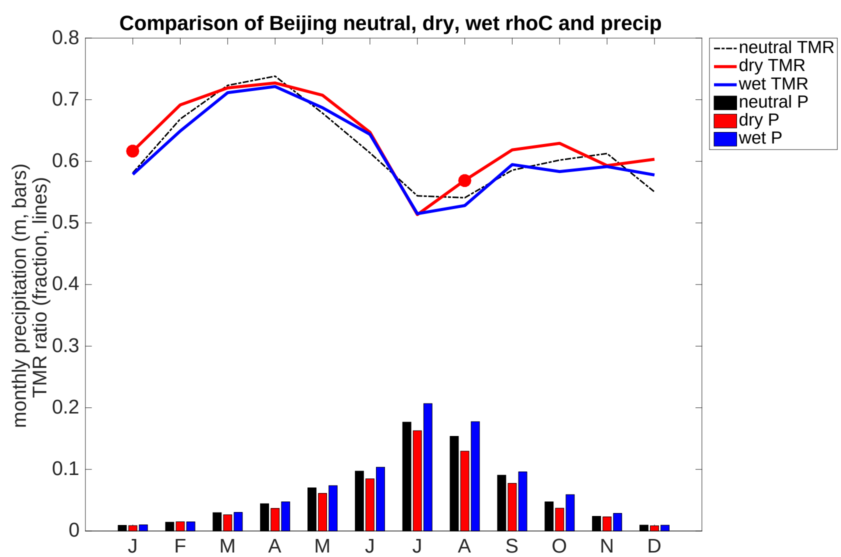

Figure S3: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Bengaluru, India

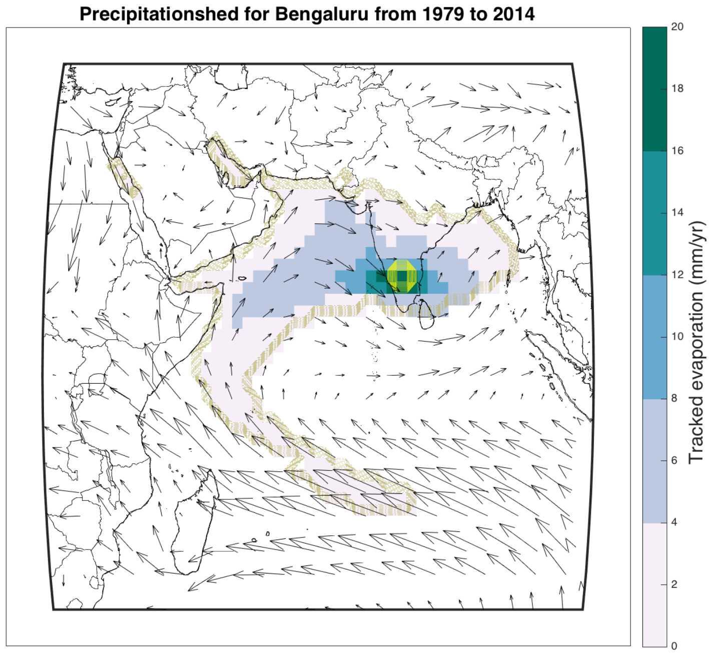

Figure S4: Bengaluru precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Bengalaru is surface water dependent, receiving 80% of water from the Cauvery river, and 20% from the Arkavathy river. Both sources of supply are erratic in their supply, with the Arkavathy suffering decreasing rainfall availability. A complex, engery-intensive network of pipes and pumps brings water uphill to Bengalaru from these reservoirs, but a growing population makes sufficient infrastructure investment difficult. Given the utter reliance on relatively small runoff-dominated basins, with limited buffer in either groundwater, inter-annual reservoir storage, or snowmelt, this megacity is highly exposed to its moisture recycling dynamics.

References

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Bengaluru, India (*continued*)

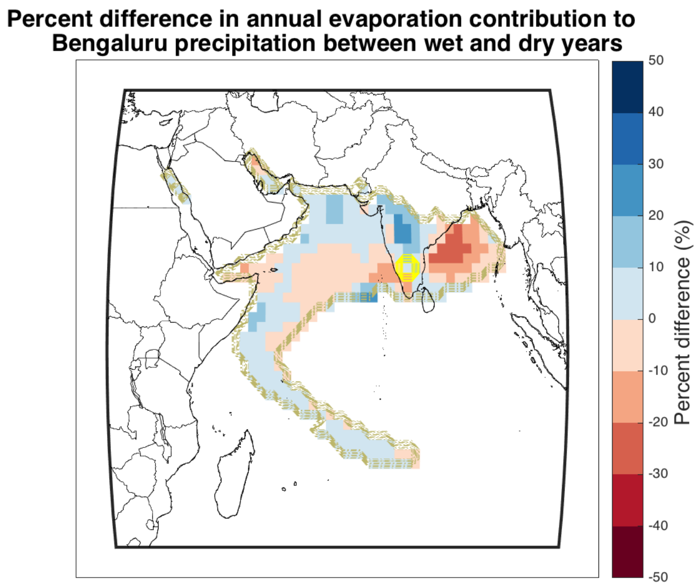

Figure S5: Percent difference in evaporation contribution between driest and wettest years.

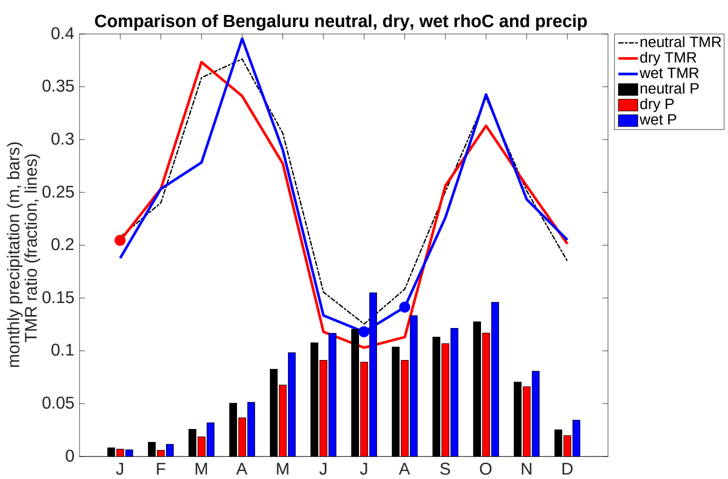

Figure S6: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Buenos Aires, Argentina

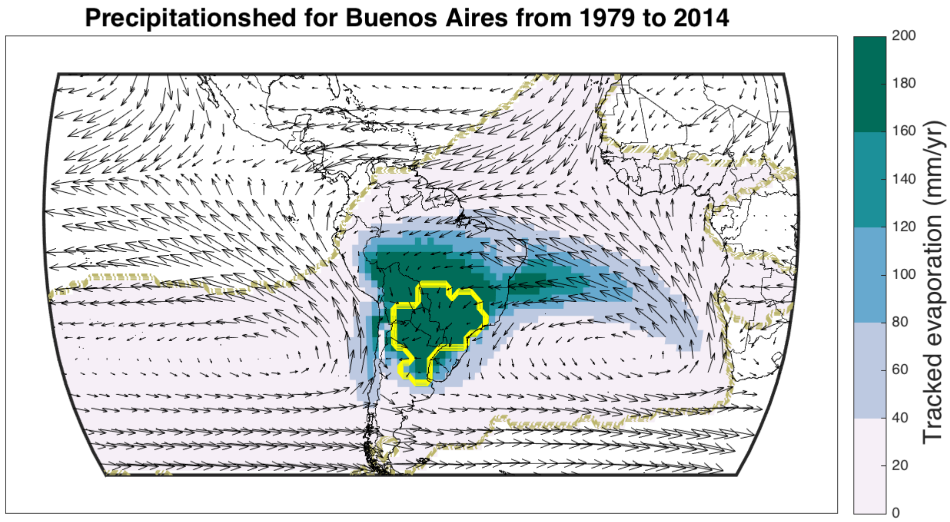

Figure S7: Buenos Aires precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Buenos Aires exists at the mouth of the Rio de La Plata, which provides around 95% of the municipal water demand for Buenos Aires. Due to lack of sewage treatment, but especially heavy industrial contamination, the La Plata is the most polluted water body in Argentina. While moisture recycling is high, including average internal moisture recycling of 23%, reliance on treated surface water for municipal supply provides a buffer against changes in moisture recycling dynamics. Thus, we suggest this megacity is moderately exposed to its moisture recycling dynamics.

References

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3. Loftus, AJ, McDonald, DA . Of liquid dreams: a political ecology of water privatization in Buenos Aires. Environment and Urbanization. 2001. 13(2), 179-199.

Buenos Aires, Argentina (*continued*)

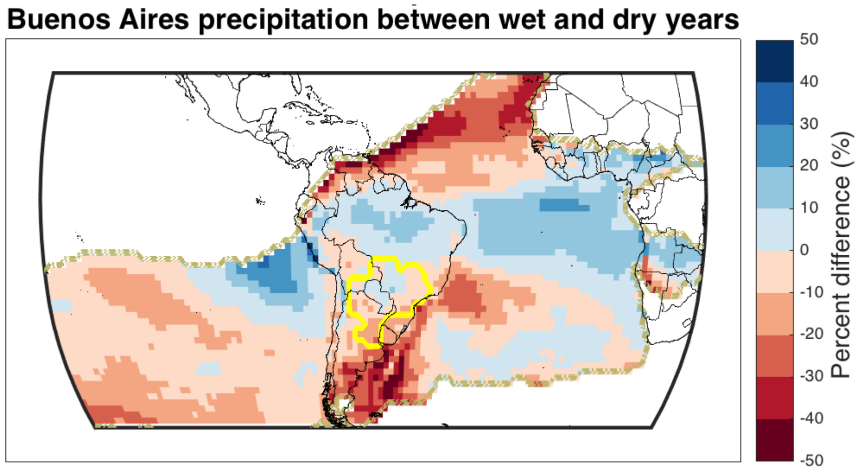

Figure S8: Percent difference in evaporation contribution between driest and wettest years.

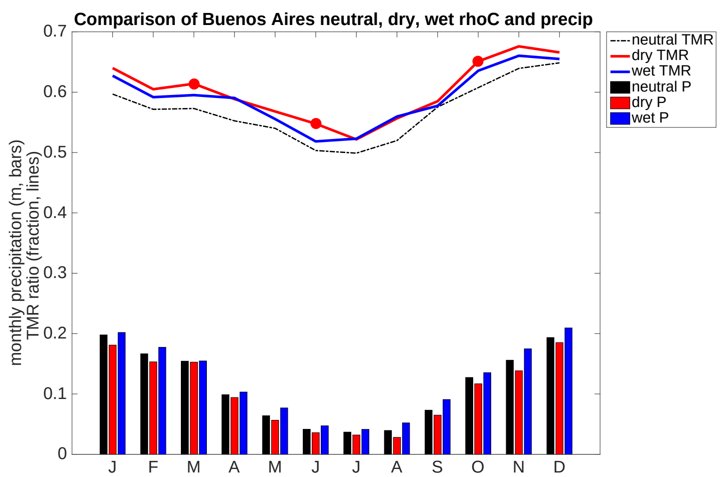

Figure S9: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Cairo, Egypt

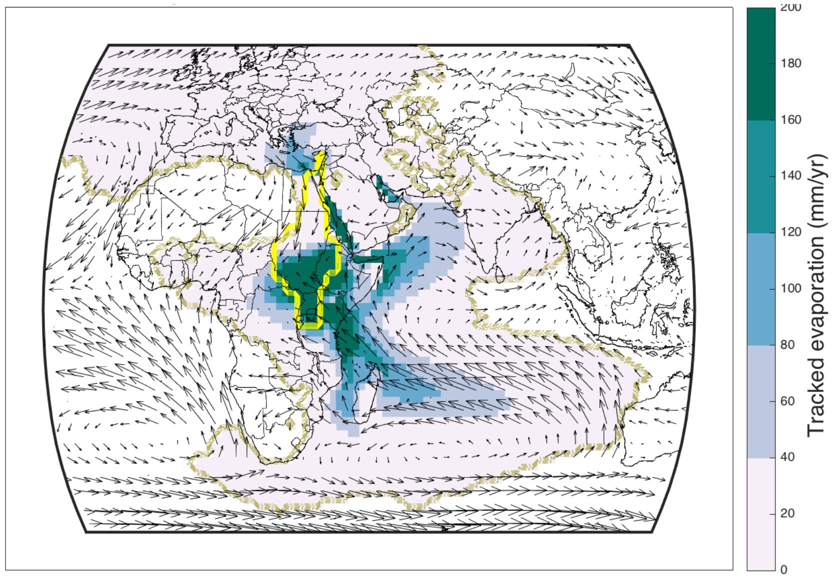

Figure S10: Cairo precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Cairo exists near the mouth of the Nile River, from which it receives nearly all of its water supply. The Aswan High Dam in southern Egypt stores approximately 1.5 times the flow of the Nile River, providing a very large water supply buffer. Despite a desert climate, and the potential decrease in Nile River flow from upstream riparians, municipal water use represents a small fraction of total water use in Egypt (around 8%). Thus, the water security of Cairo has some buffer, i.c. shifting water uses and adequate storage. However, the uncertainty of upstream Nile Basin country behavior (including Ethiopia which is constructing a very large dam that will retain a significant fraction of the Blue Nile), and the reliance on the Nile for surface runoff generated by significant internal moisture recycling within the Nile watershed itself, suggests that Cairo is moderately exposed to its moisture recycling dynamics.

References

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Cairo, Egypt (*continued*)

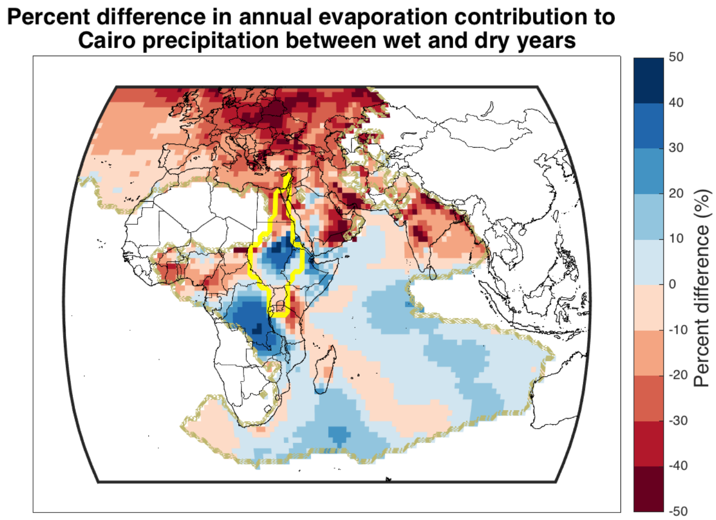

Figure S11: Percent difference in evaporation contribution between driest and wettest years.

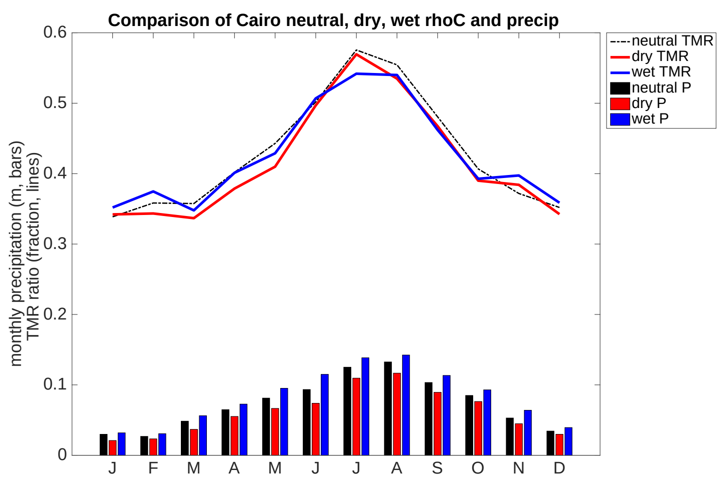

Figure S12: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Chongqing, China

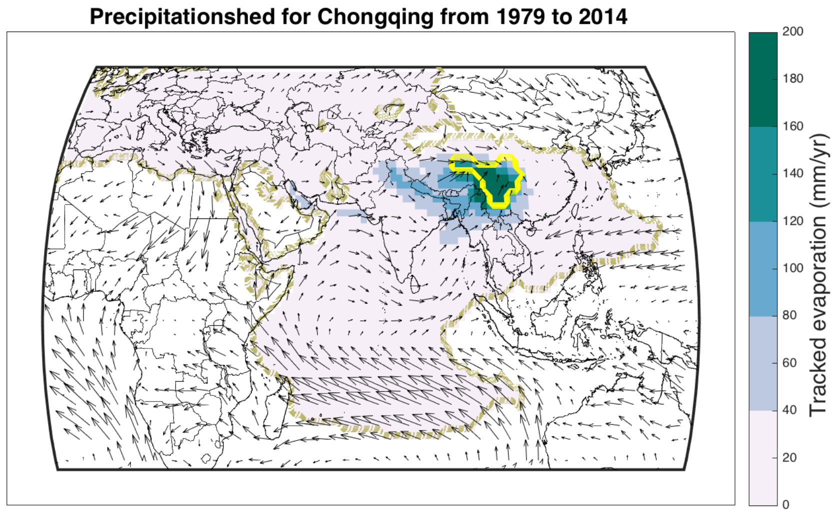

Figure S13: Chongqing precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Chongqinq is the primary city near the Three Gorges Dam on the Yangtze River. Despite the proximity to the dam, significant agricultural pollution and supply shortfalls plague the city. The primary issues of water security are rapid economic growth and demographic change, while a primary driver of stability in the water security is the forest cover in the basin. Given the dependence on surface water, the apparent importance of trees in helping regulate this water, and the importance of internal watershed moisture recycling, we consider Chongqing to be highly exposed to its moisture recycling dynamics.

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Chongqing, China (*continued*)

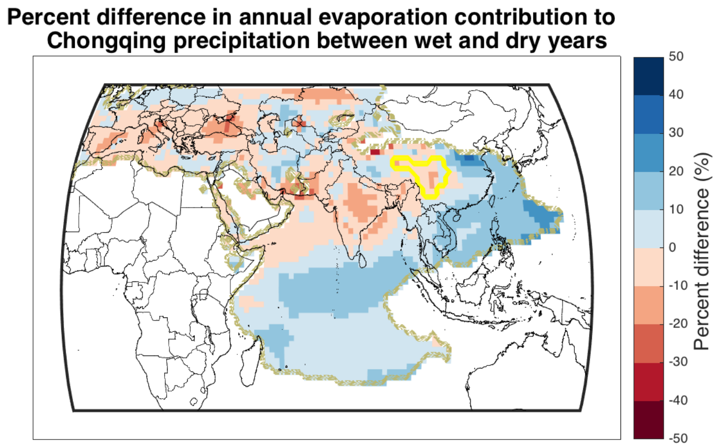

Figure S14: Percent difference in evaporation contribution between driest and wettest years.

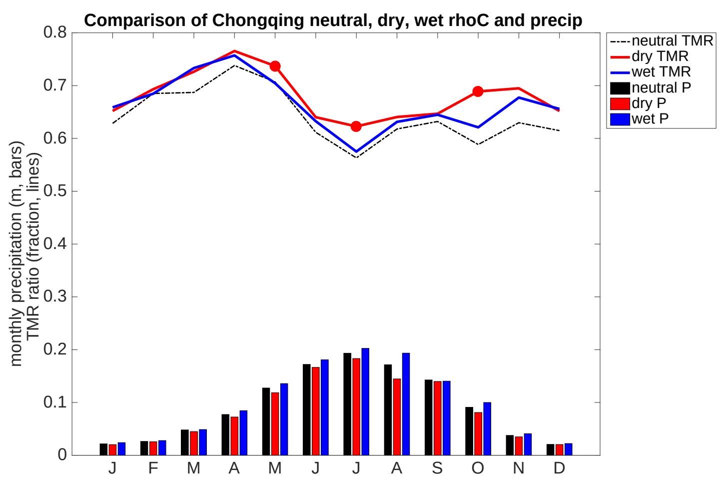

Figure S15: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Delhi, India

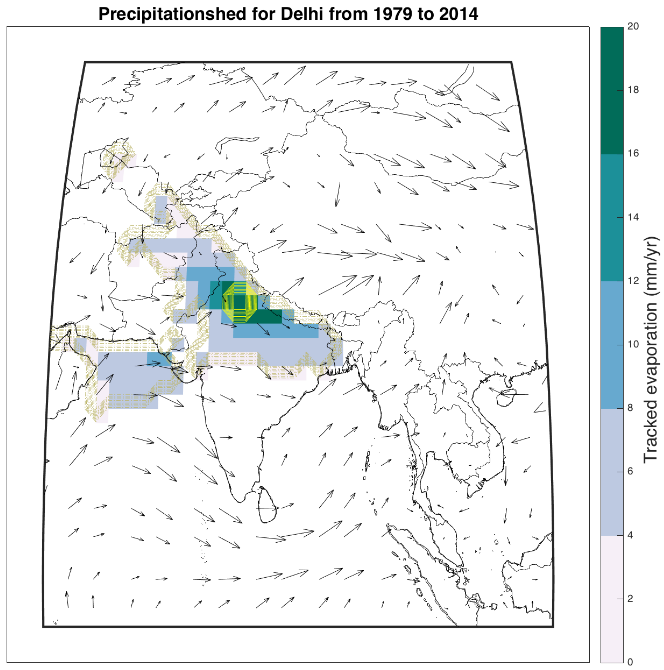

Figure S16: Delhi precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Delhi is a very water scarce city that relies primarily on runoff from the Yamuna River in Northern India. The Yamuna experiences relatively high moisture recycling, and the demand on the water from the Yamuna far exceeds the supply. In recent years there is strong evidence of very signifcant sensitivity of local water security to below-normal rainfall years, which has even led to security concerns of the canal that connects Delhi to important Yamuna reservoirs. Thus, the low storage buffer, the importance of terrestrial moisture recycling, and the high reliance on surface runoff, suggest that Delhi's water security is highly exposed to moisture recycling dynamics.

References

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Delhi, India (*continued*)

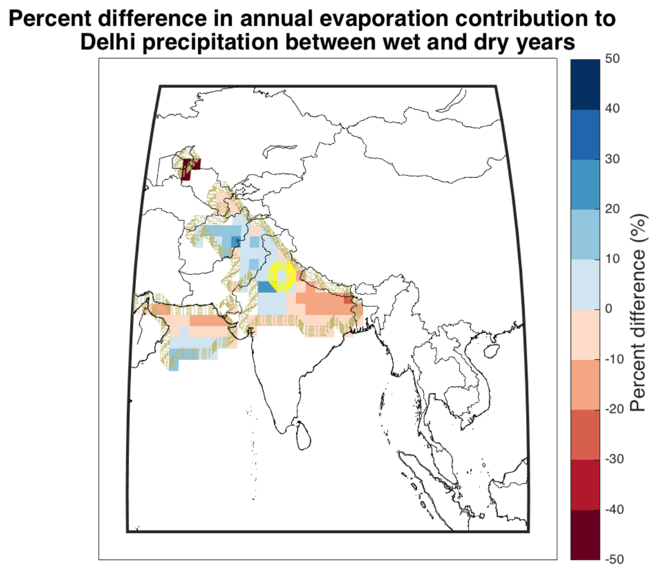

Figure S17: Percent difference in evaporation contribution between driest and wettest years.

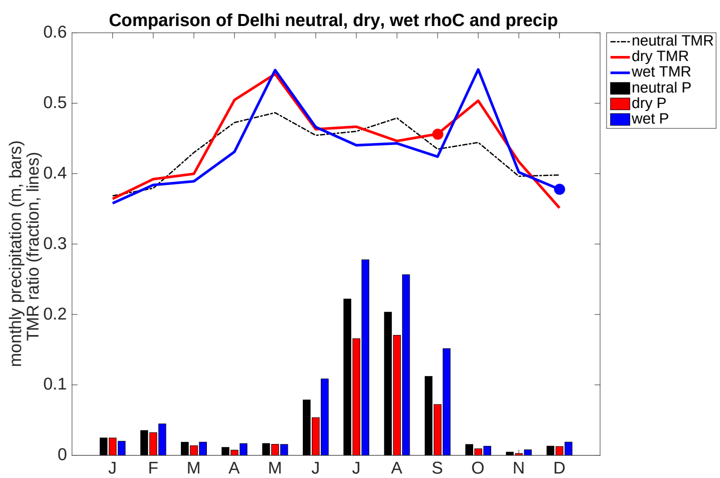

Figure S18: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Dhaka, Bangladesh

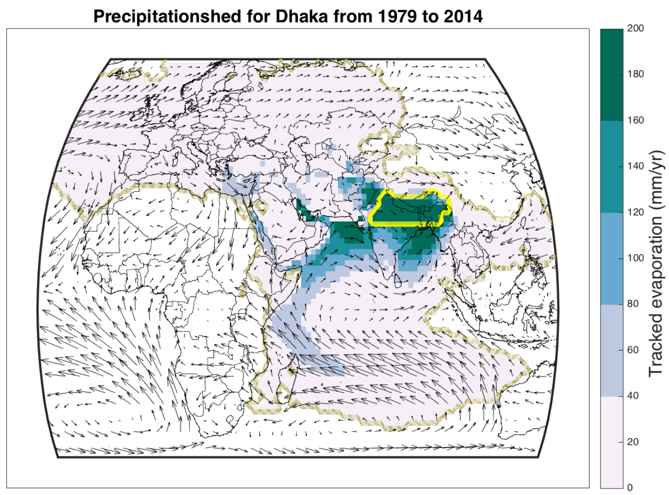

Figure S19: Dhaka precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Dhaka is located in one of the world's largest river deltas, at the confluence of the Ganges, Brahamputra, and Meghna rivers. However, much of the surface water nearby is heavily polluted, and thus much of the municipal water supply comes from actively re-charged groundwater. Recent efforts to augment household level water supply, by encouraging small-scale rainwater harvesting, are aimed at mitigating reliance on groundwater, though these efforts are very new. In terms of moisture recycling, Dhaka's most important terrestrial sources of precipitation come from the Tibetan plateau, and it is here that key land-use changes would, theoretically, need to be monitored. However, the overwhelming dependence on actively recharged groundwater suggests a significant buffer to surface water change in Dhaka, leading to low exposure to moisture recycling change.

References

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Dhaka, Bangladesh (*continued*)

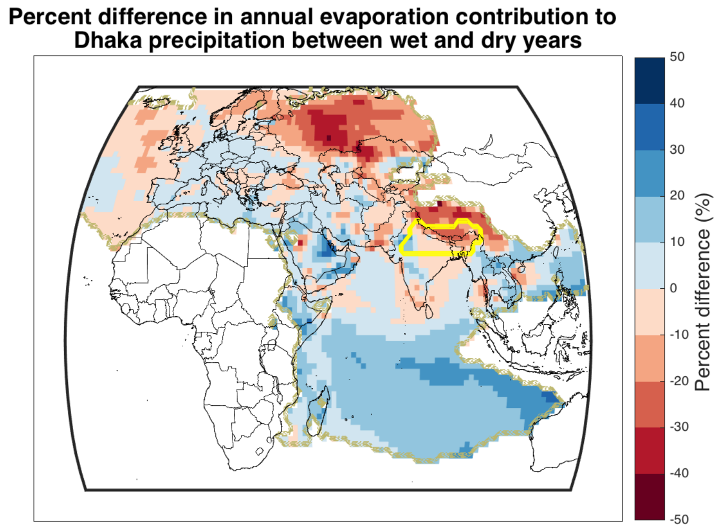

Figure S20: Percent difference in evaporation contribution between driest and wettest years.

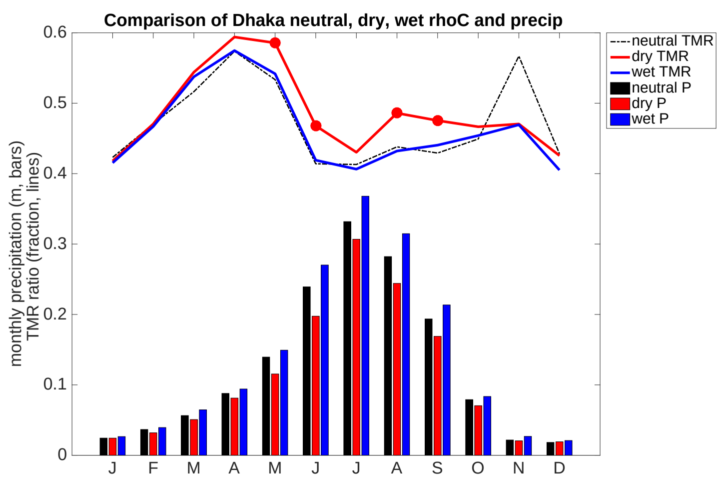

Figure S21: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Guangzhou, China

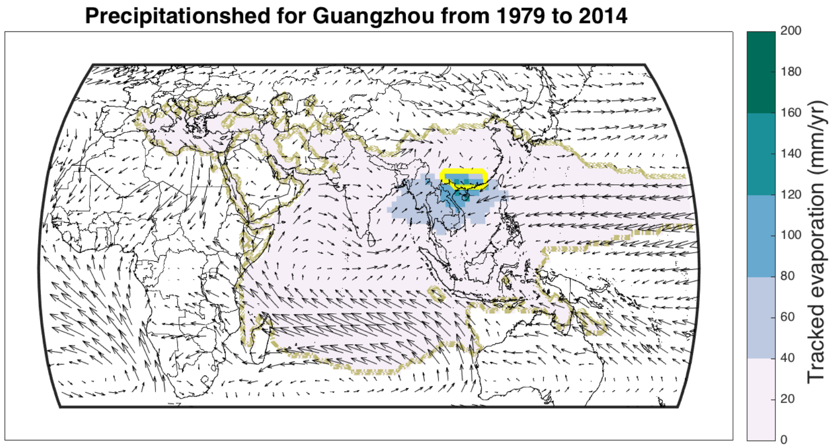

Figure S22: Guangzhou precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Guangzhou is one of China's key megacities, and is located in the Pearl River Delta. It receives about 80% of water from surface runoff, which is heavily polluted from agricultural runoff, industrial effluent, and human waste upstream. Gaungzhou receives water from the western (Xi) and Northern (Bei) tributaries, and the primary issue for water security is managing water quality. Although the Pearl River is a large river, the supply of water available is dwindling due to ever growing demands for freshwater both upstream and in the Pearl River Delta. Thus, any changes in moisture recycling are likely to be felt quite quickly given the limited buffers that exist. Thus, we argue that Guangzhou's water security is moderately exposed to moisture recycling dynamics.

References

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Guangzhou, China (*continued*)

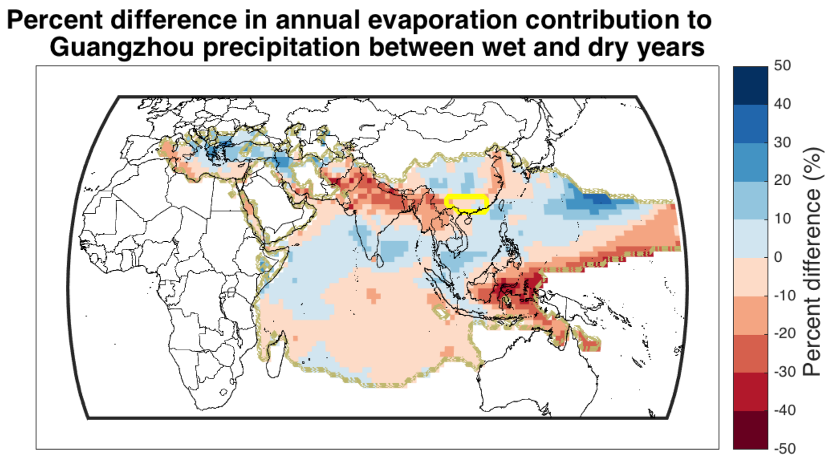

Figure S23: Percent difference in evaporation contribution between driest and wettest years.

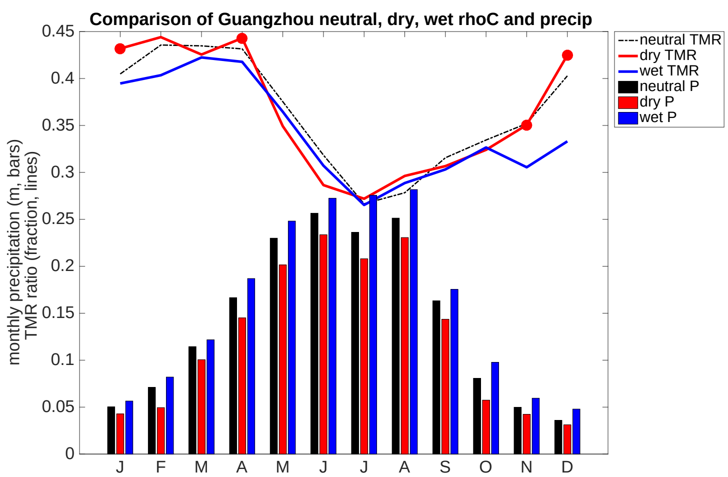

Figure S24: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Istanbul, Turkey

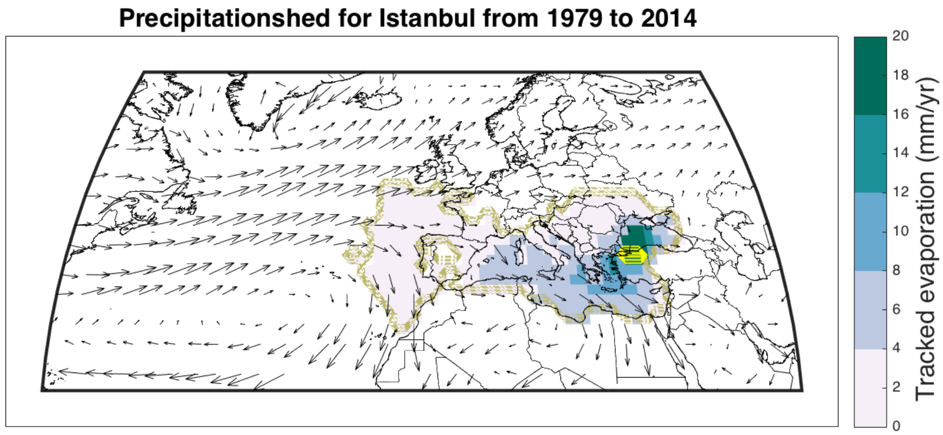

Figure S25: Istanbul precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Istanbul is located in a narrow isthmus betwen the Mediterranean Sea and the Black Sea. 97% of water supply comes from two reservoirs systems: the Omerli-Darlik in the east, and the Terkos-Alibeykov in the west. The reservoir networks are located almost entirely within the metropolis, and informal settlements around the reservoirs lead to pollution problems. Planned development of expanded water supply will only just keep pace with growth in demand. Furthermore, several studies have found that Istanbul is sensitive to drought periods. Thus, we consider Istanbul to be highly exposed to changes in moisture recycling.

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Istanbul, Turkey (*continued*)

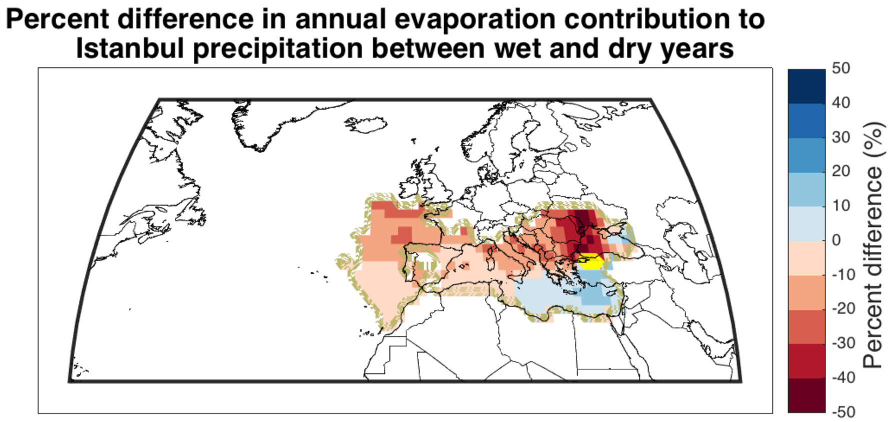

Figure S26: Percent difference in evaporation contribution between driest and wettest years.

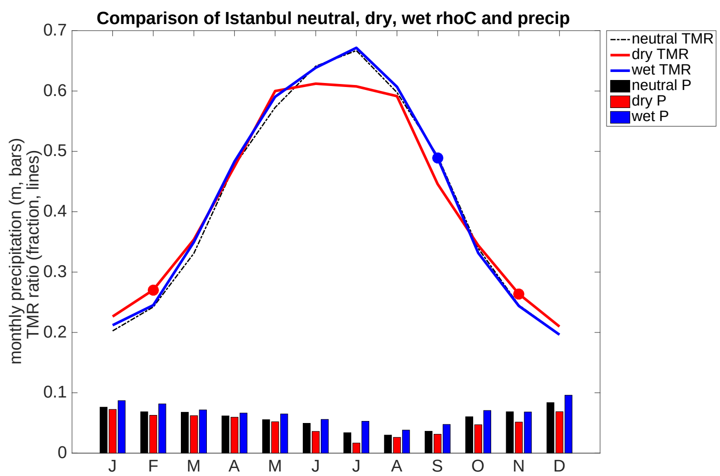

Figure S27: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Jakarta, Indonesia

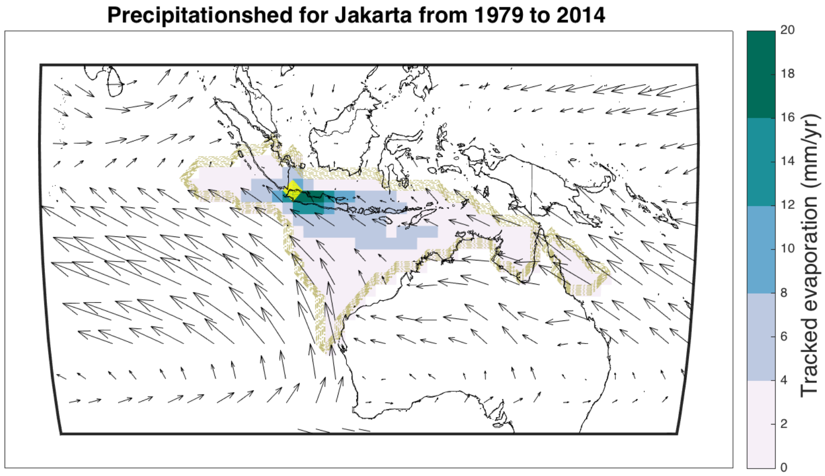

Figure S28: Jakarta precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Jakarta receives most of its municipal water (80%) from surface runoff from the Citarum river to the east, transported via the West Tarum canal. The water supplied to the city is distributed unevenly with large gaps in access between the rich and the poor. The water supply seems to be stable and the biggest issue is improving infrastructure and piped connections. Though moisture recycling may be affected by ongoing land-use change, the dominance of oceanic sources of moisture (versus land sources) suggests that Jakarta has low exposure to moisture recycling dynamics.

References

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Jakarta, Indonesia (*continued*)

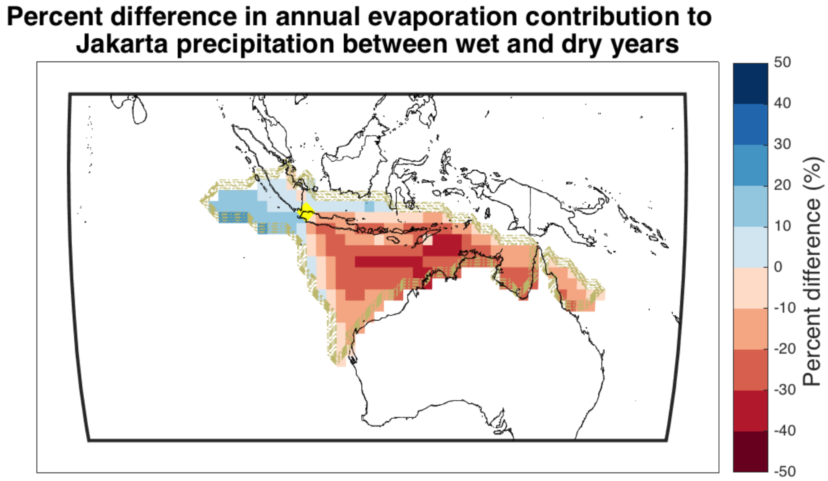

Figure S29: Percent difference in evaporation contribution between driest and wettest years.

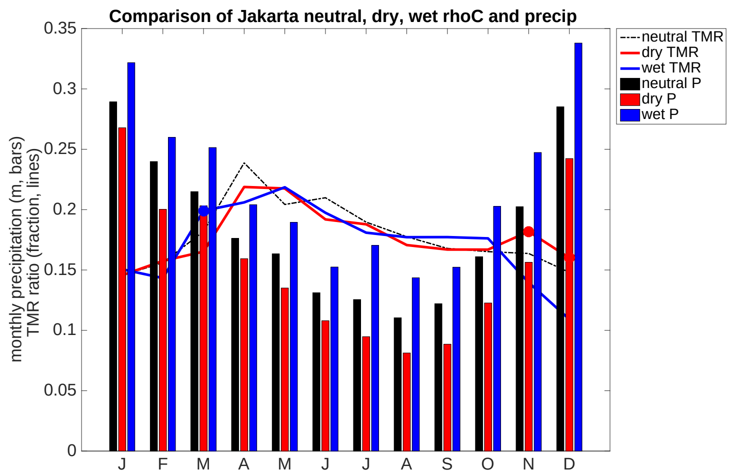

Figure S30: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Kolkata, India

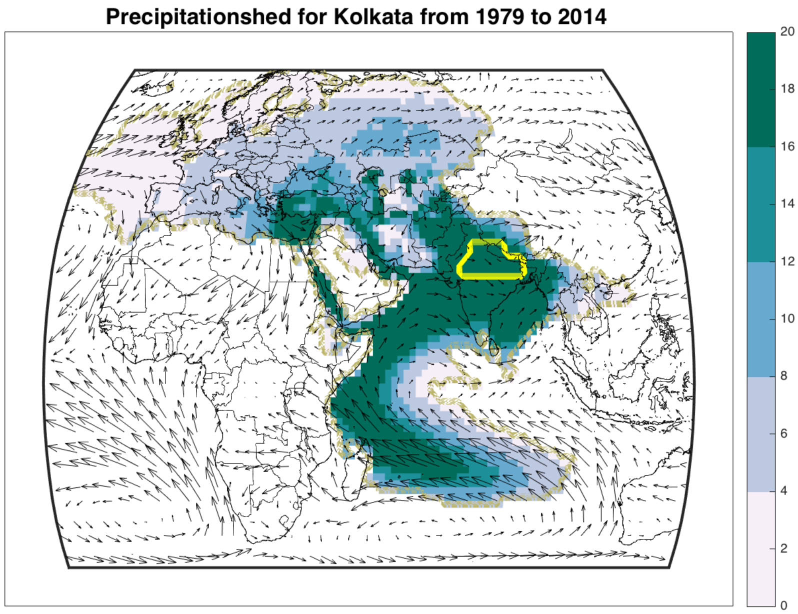

Figure S31: Kolkata precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Kolkata receives most of its water from the Hooghly River, a distributary of the Ganges River. There is relatively reliable flow and modern infrastructure enables considerably better water availability than in many other Indian cities. Flooding is one of the key water-related problems in Kolkata, and combined with the large size of the basin, the blended snowmelt and runoff system, the exposure to moisture recycling dynamics and water security is considered low.

References

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Kolkata, India (*continued*)

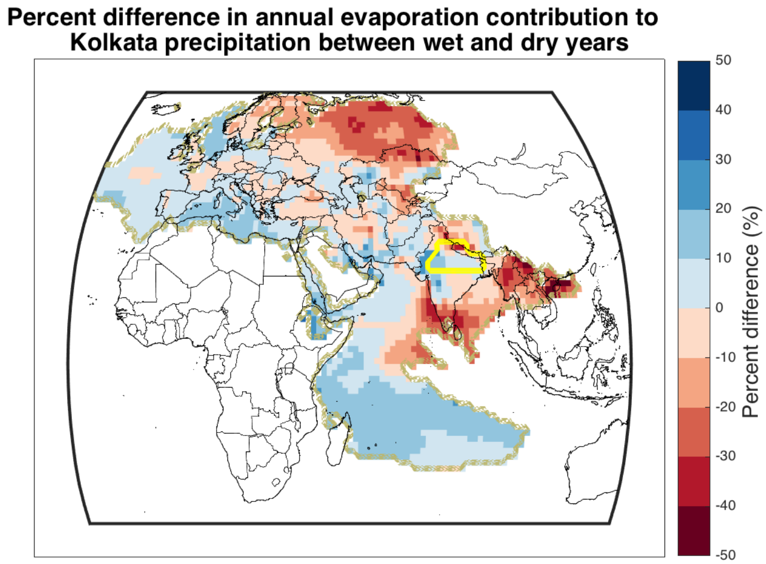

Figure S32: Percent difference in evaporation contribution between driest and wettest years.

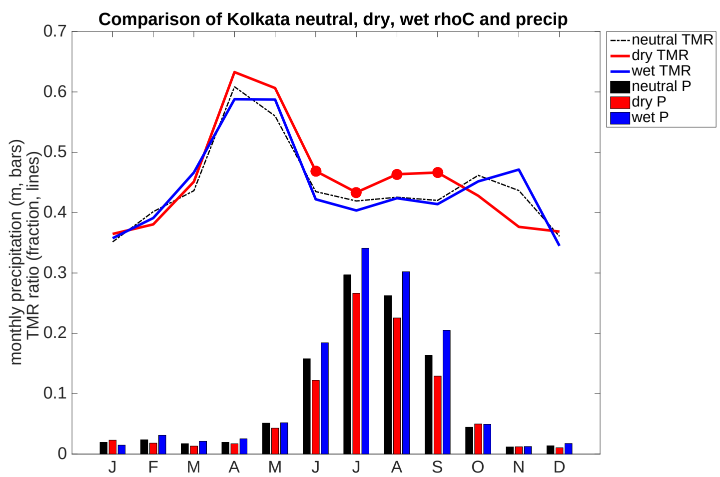

Figure S33: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Lagos, Nigeria

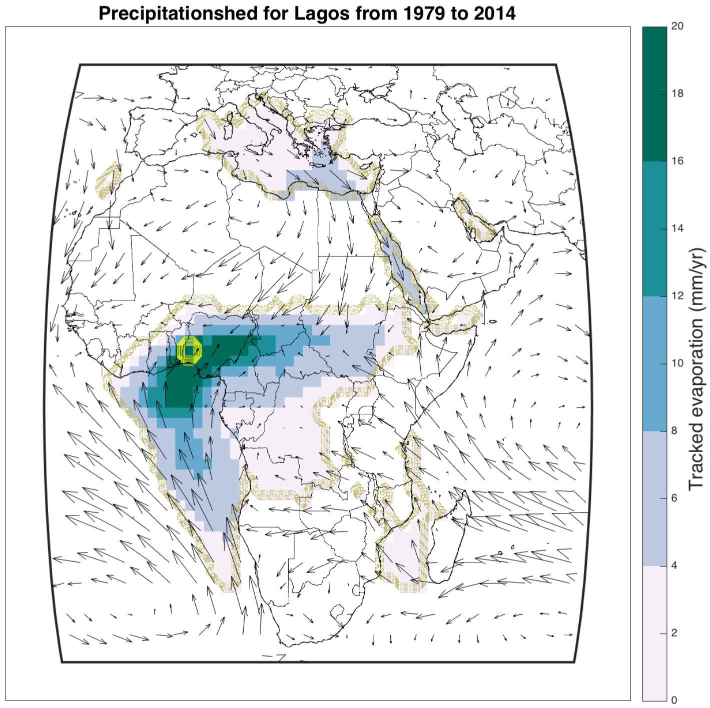

Figure S34: Lagos precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Lagos is a coastal city that relies on surface runoff from the Ogun River (in addition to several other smaller rivers). Recent analyses suggest that only 10% of Lagos residents receive piped water, suggesting an enormous infrastructure and management challenge. However, there is considerable rainfall of terrestrial origin, and there is little to no reservoir storage to provide a buffer. Thus, given the immediacy of impact from changes in rainfall felt in the population, Lagos is considered highly exposed to moisture recycling dynamics.

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Lagos, Nigeria (*continued*)

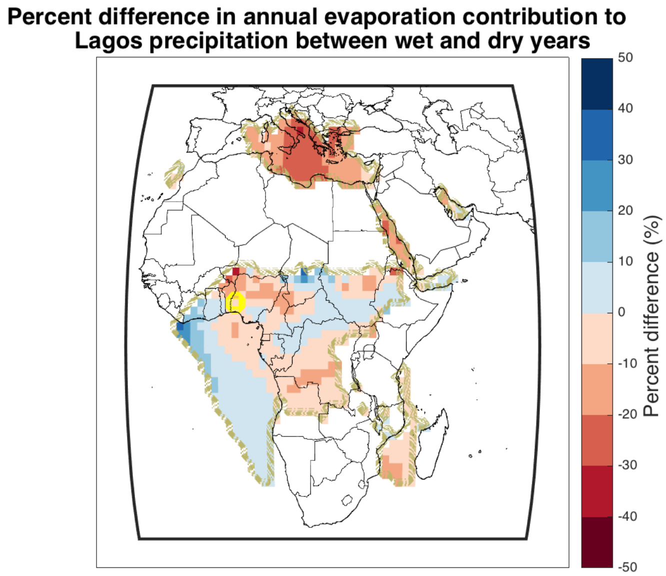

Figure S35: Percent difference in evaporation contribution between driest and wettest years.

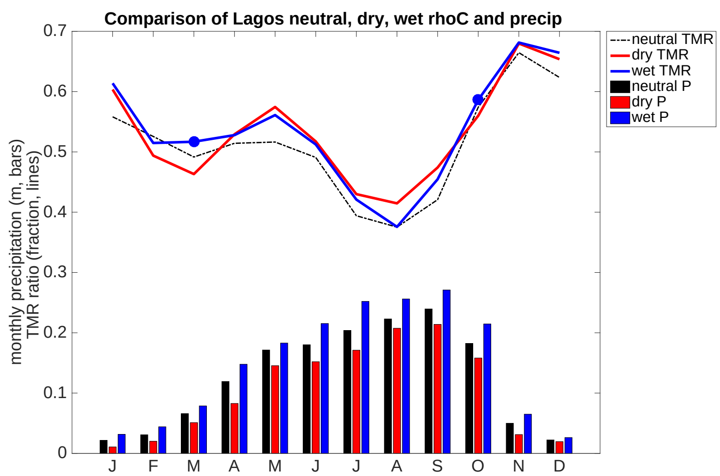

Figure S36: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Los Angeles, USA

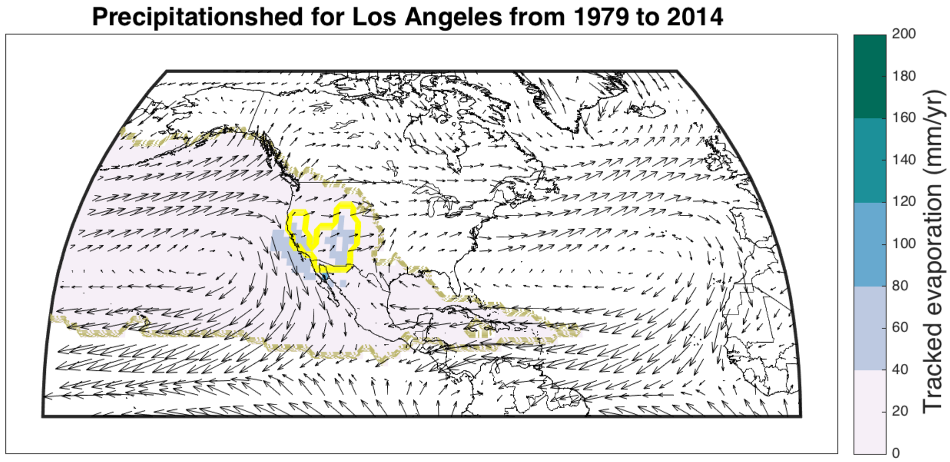

Figure S37: Los Angeles precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Los Angeles, unlike many megacities, receives water from numerous watersheds across the southwestern United States, including the Colorado River, the Owens River, and the San Joaquin-Sacramento River. All of these water resources are fully- or over-allocated. Much of the Californian water passes through both desert and agricultural land, while the Colorado River is snowmelt passing through the harshest deserts in the United States. Despite the arid climate and the over-allocation, there is some amount of buffer within the system to re-allocate water from agriculture to municipal uses, and the prospect of moisture recycling change impacting Los Angeles' water resources appears moderate, so we consider Los Angeles to be moderately exposed to moisture recycling dynamics.

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Los Angeles, USA (*continued*)

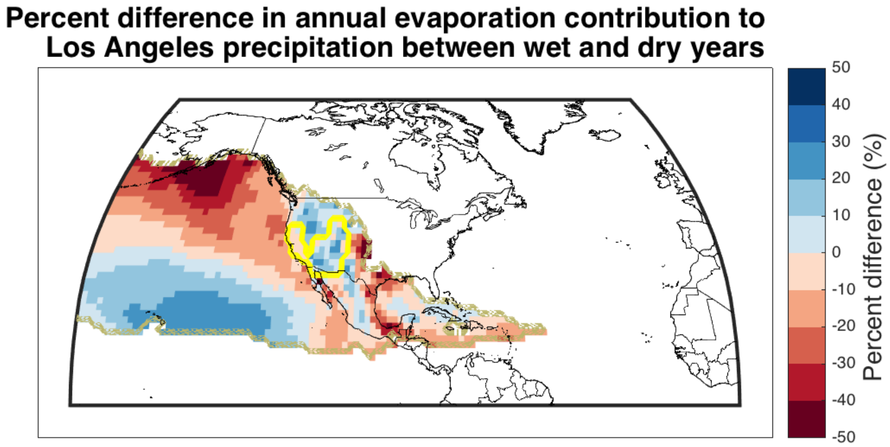

Figure S38: Percent difference in evaporation contribution between driest and wettest years.

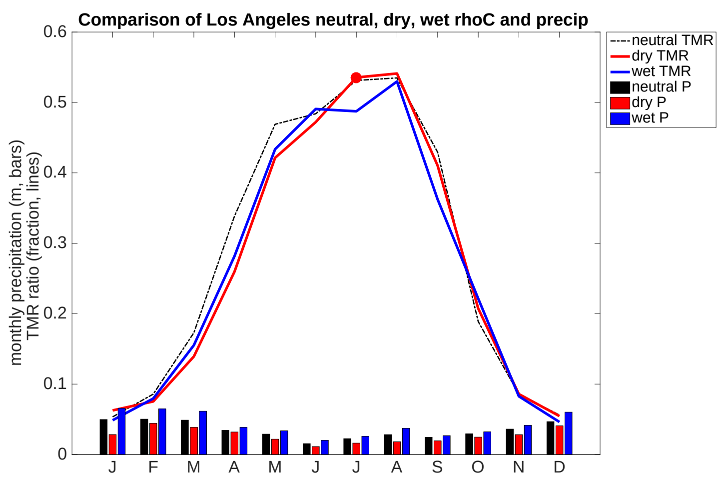

Figure S39: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Manila, Philippines

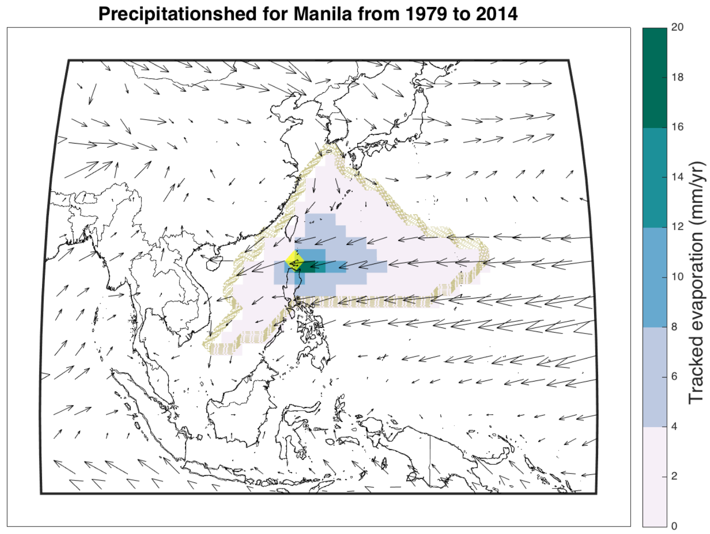

Figure S40: Manila precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Manila is served by the Angat-Ipo-La Mesa water system, with the Angat Dam providing about 90% of the water for Metro Manila. The watershed for the reservoir is relatively small, but highly protected providing good source water protection. The importance of moisture recycling is relatively low, with internal moisture recycling being nearly negligible. Given the well-protected design of the water supply and the low importance of terrestrial moisture recycling, Manila's exposure to moisture recycling change is considered low.

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Manila, Philippines (*continued*)

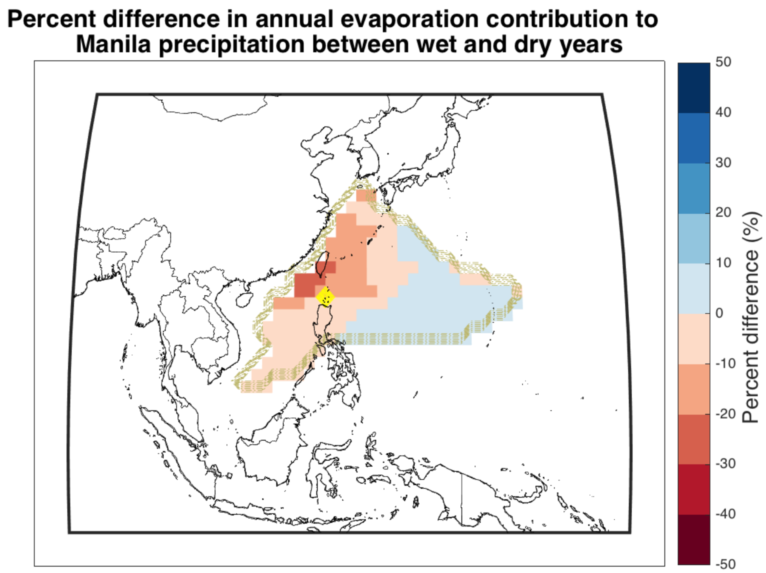

Figure S41: Percent difference in evaporation contribution between driest and wettest years.

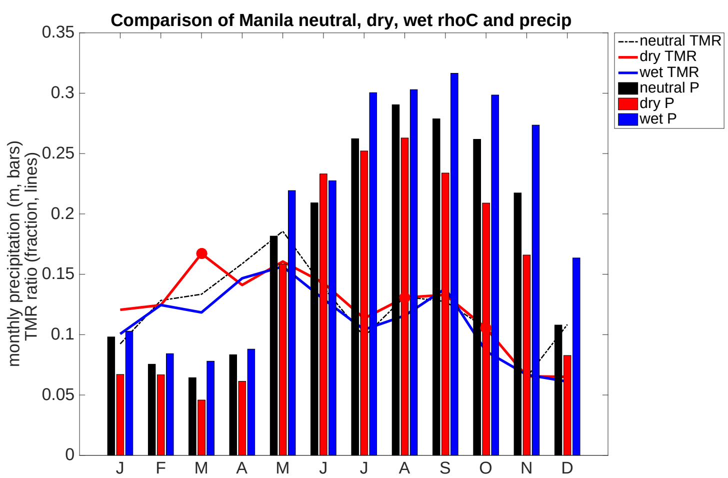

Figure S42: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Mexico City, Mexico

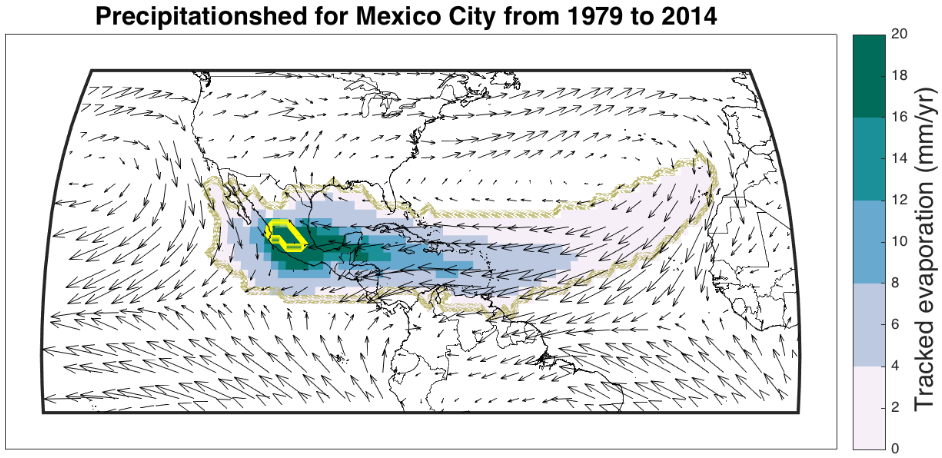

Figure S43: Mexico City precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Mexico City is primarily reliant on actively recharged groundwater supplies including private wells, supplemented by about 20% from the nearby Cutzamala River. The rapid growth of Mexico City has taxed groundwater supplies, leading to over-exploitation, land subsidence, and falling groundwater tables. Mexico City is semi-arid, and is rapidly growing, and will be increasingly reliant on surface water resources (though from where it is unclear). If groundwater is channeled through centralized systems and water supply networks, moisture recycling exposure would by low. However, given that the population is in direct access of the water cycle (via distributed, actively recharged groundwater wells), and that terrestrial moisture recycling is relatively high (30%), we suggest that Mexico City is moderately exposed to moisture recycling dynamics.

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Mexico City, Mexico (*continued*)

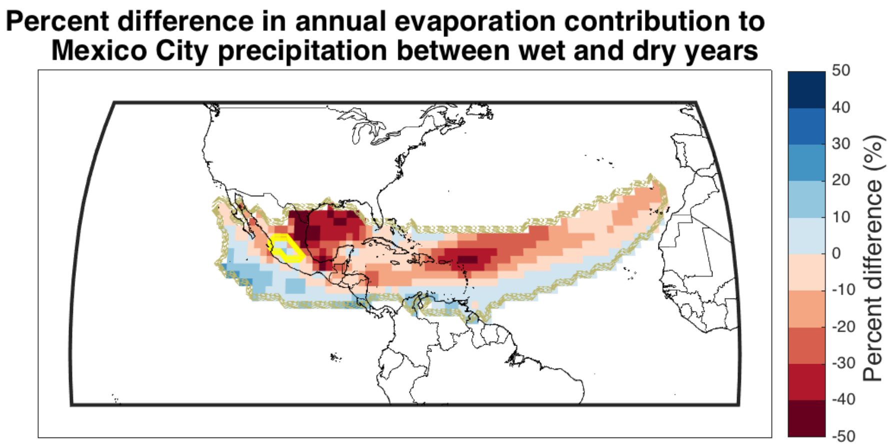

Figure S44: Percent difference in evaporation contribution between driest and wettest years.

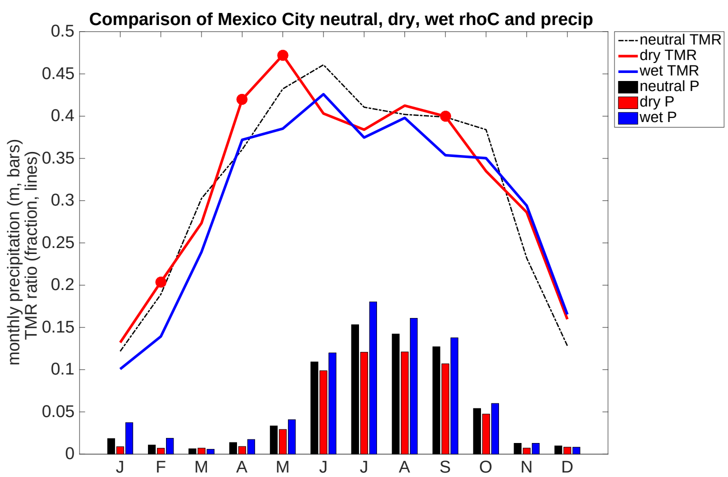

Figure S45: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Moscow, Russia

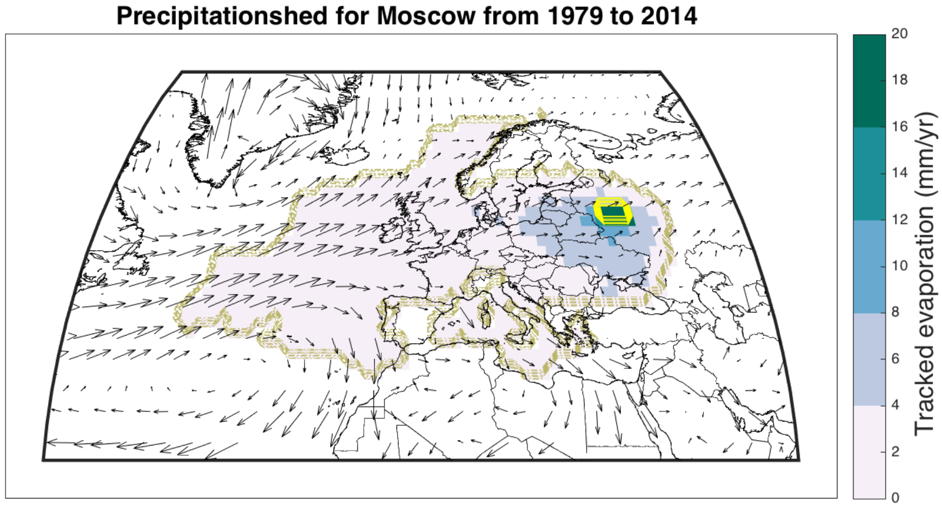

Figure S46: Moscow precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Moscow receives most of its freshwater from the Ivankovo Reservoir on the upper reaches of the Volga River. There are no other major sources of water supply to Moscow. Both terrestrial moisture recycling and vegetation-regulated moisture recycling are high. Historically, landscapes in the Upper Volga have been quite sensitive to dry and wet years, leading to extensive forest loss and fires. Furthermore, there is a high potential for land-use change (anthropogenic or natural) from e.g. agricultural change and forest fire. All of these conditions suggest Moscow is highly exposed to changes in moisture recycling.

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Moscow, Russia (*continued*)

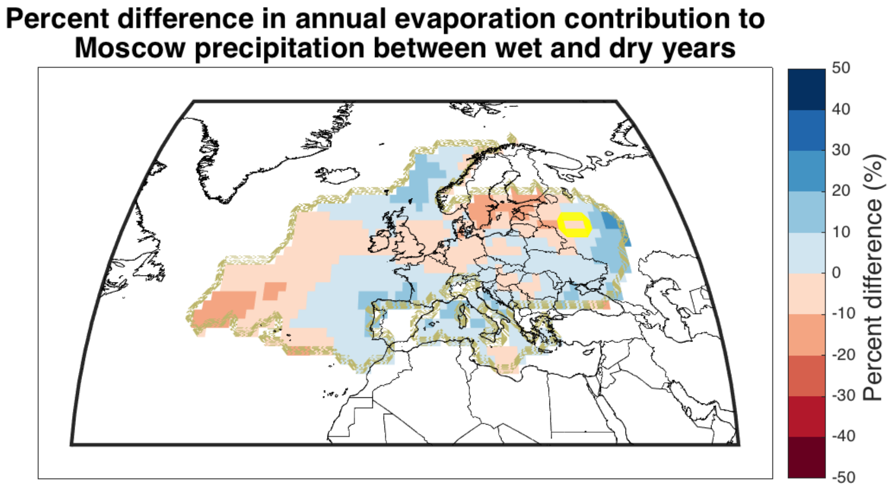

Figure S47: Percent difference in evaporation contribution between driest and wettest years.

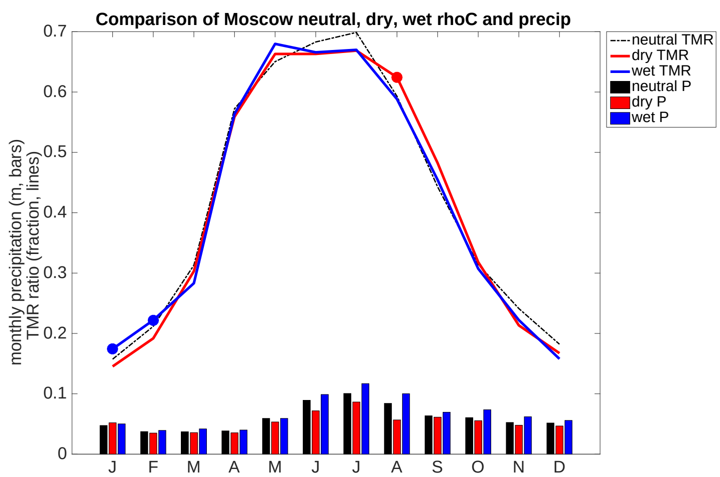

Figure S48: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Mumbai, India

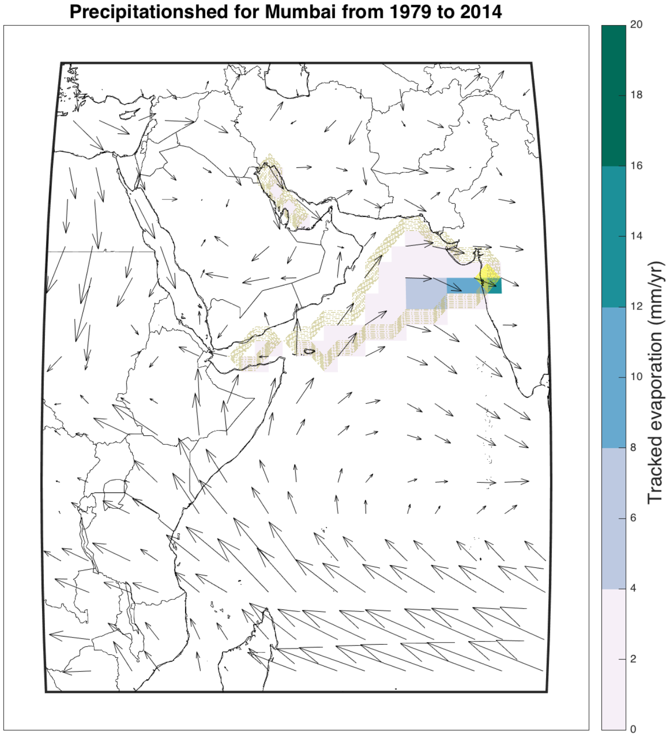

Figure S49: Mumbai precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Mumbai receives its water from several rivers running off the Western Ghat Mountains, and is primarily stored in the Bhandup reservoir complex. The importance of moisture recycling for this rainfall is relatively high, and though the runoff is supplied by Monsoon rains, dry seasons can be particularly risky leaving reservoirs empty. We consider Mumbai to be highly exposed to moisture recycling dynamics.

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Mumbai, India (*continued*)

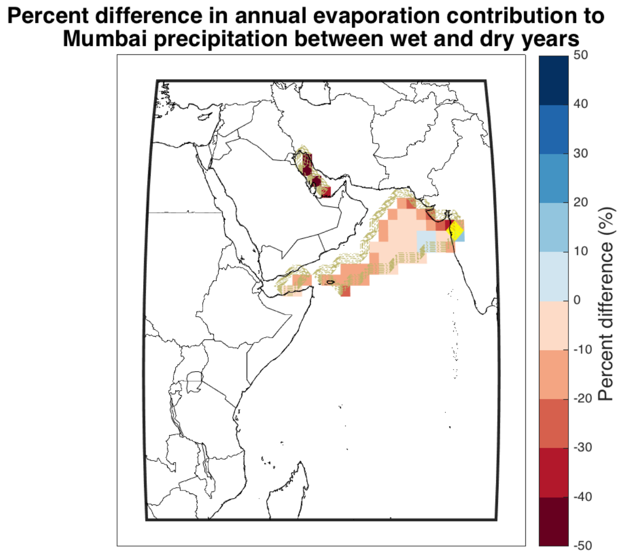

Figure S50: Percent difference in evaporation contribution between driest and wettest years.

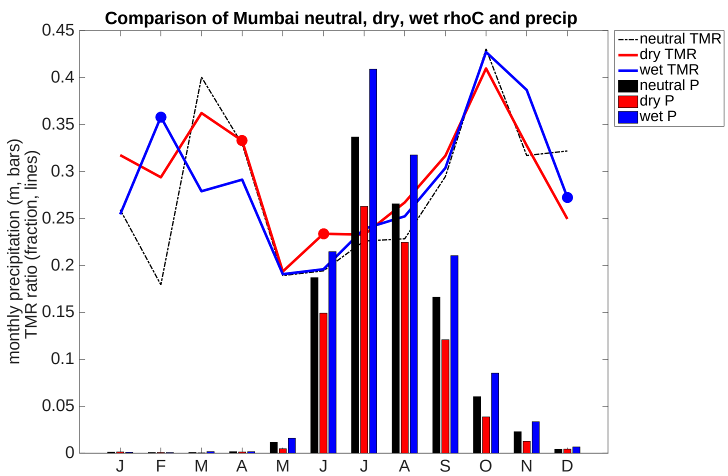

Figure S51: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

New York City, USA

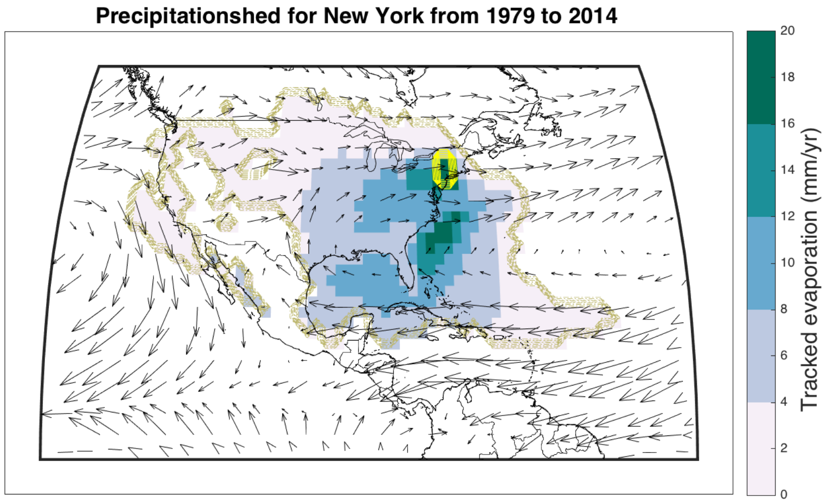

Figure S52: New York City precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

New York City receives 90% of its water from the Catskill Mountains via the Catskill Aqueduct and the Delaware Aqueduct. The watersheds are very well protected from development and pollution, providing excellent benefits in terms of water quality. The city has experienced drought somewhat recently leading to mandatory water conservation efforts. Given this drought sensitivity, the reliance on surface runoff from one region, and the relatively high moisture recycling values, we consider New York City to be highly exposed to its moisture recycling dynamics .

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New York City, USA (*continued*)

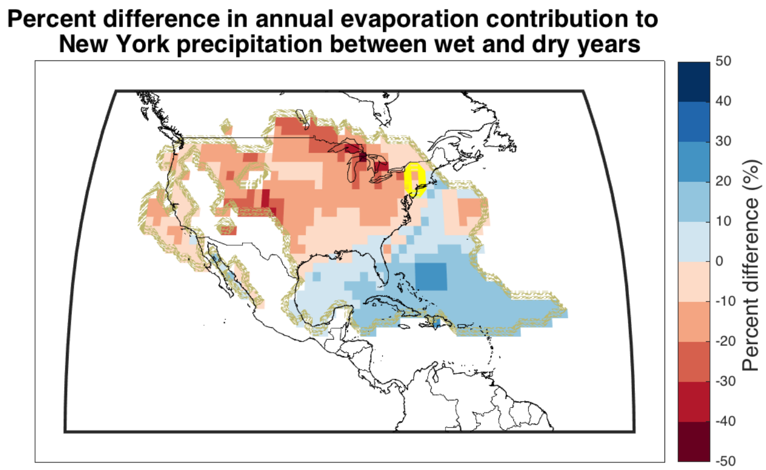

Figure S53: Percent difference in evaporation contribution between driest and wettest years.

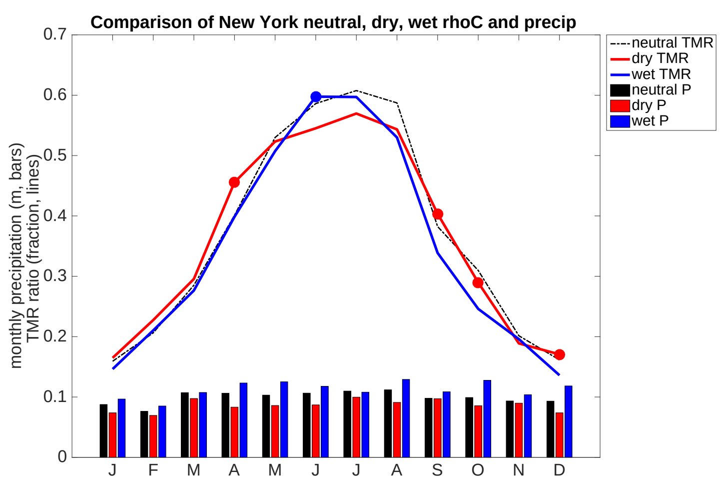

Figure S54: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Osaka-Kobe, Japan

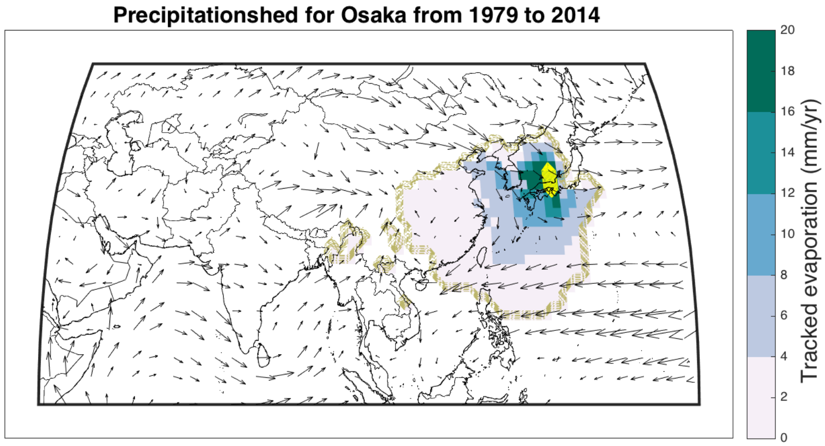

Figure S55: Osaka-Kobe precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

The Osaka-Kobe metropolitan area receives its water from the Kyu-Yodo River, flowing out of Lake Biwa. This river supplies water to many other downstream users, though streamflow seems to be less sensitive to drought, and water management is state-of-the-art and efficient. Given the reliance on surface runoff, the moderate reliance on terrestrial evaporation, and the buffers in water storage in the water management system, we consider Osaka-Kobe to be moderately exposed to moisture recycling dynamics.

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Osaka-Kobe, Japan (*continued*)

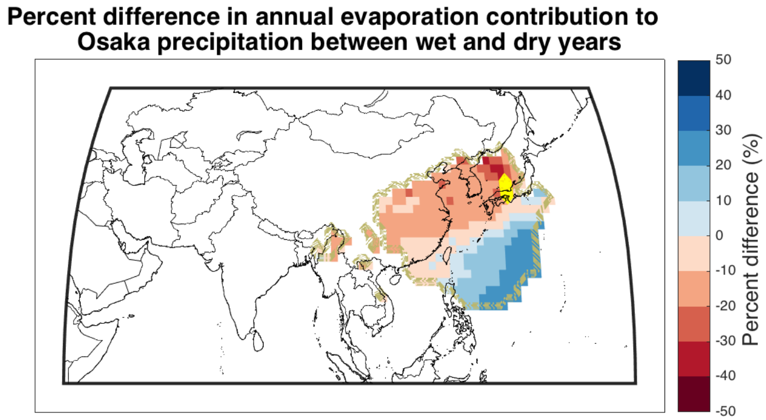

Figure S56: Percent difference in evaporation contribution between driest and wettest years.

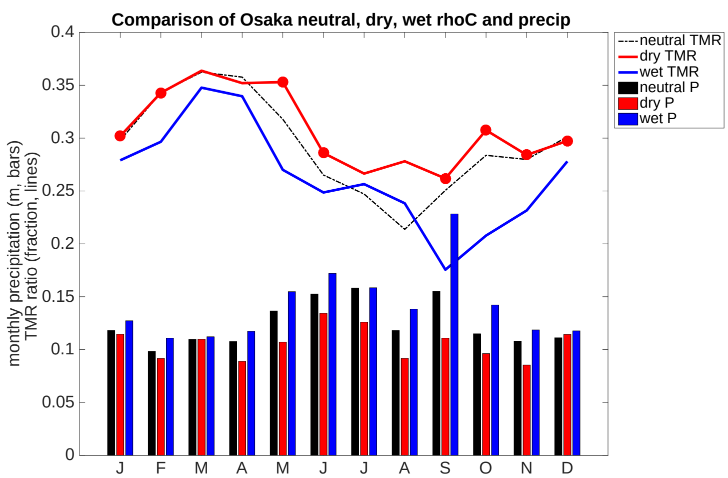

Figure S57: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Paris, France

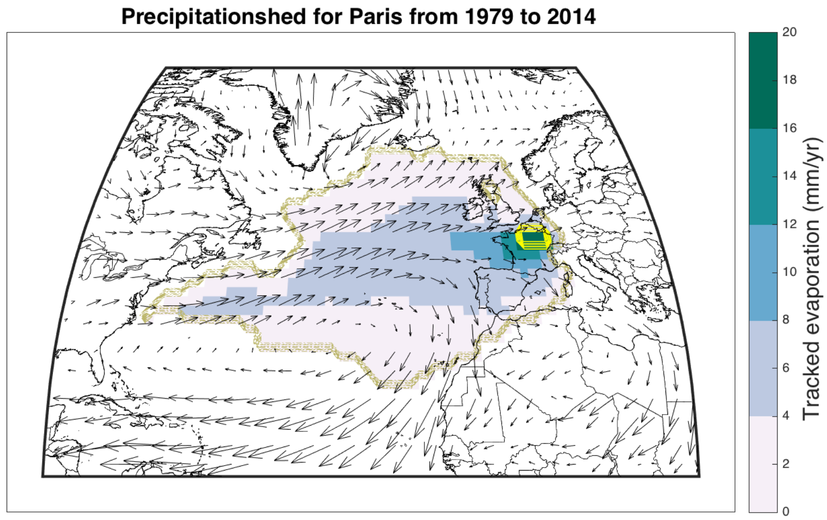

Figure S58: Paris precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Paris receives its water from a dense network of surface and groundwater supplies, transported via tunnel and aqueduct and stored in both above- and below-ground reservoirs. Moisture recycling rates are relatively high, with significant recycling occurring within France itself. The distributed nature of the supply points, however, does not necessarily reduce the overall connection to moisture recycling, so we consider Paris' water security is moderately exposed to moisture recycling.

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Paris, France (*continued*)

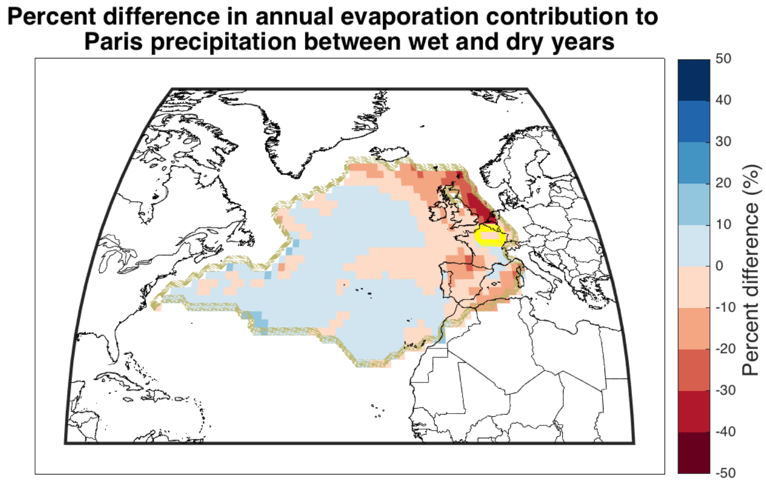

Figure S59: Percent difference in evaporation contribution between driest and wettest years.

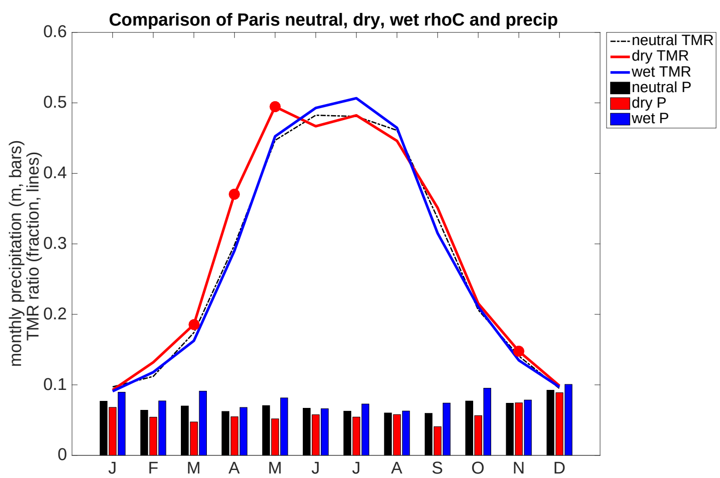

Figure S60: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Rio de Janeiro, Brazil

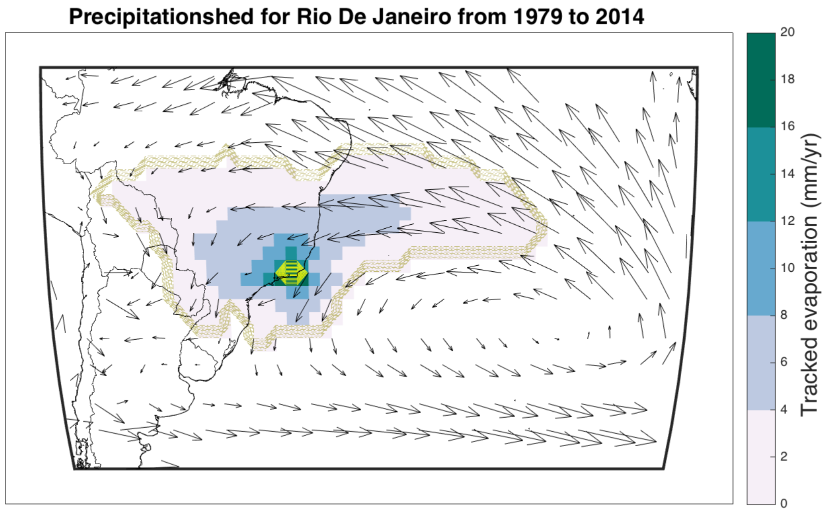

Figure S61: Rio de Janeiro precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Rio de Janeiro receives most of its drinking water from the Guandu River and a portion of the Paraiba do Sul River. This surface runoff is generated locally, and is in a region with very high (and growing) water demand. Moisture recycling is relatively high, as is vegetation-regulation of this moisture recycling, but it occurs primarily outside of the watershed. Given the reliance on surface runoff, the high moisture recycling ratios, and the vulnerability of water security to drought, we consider Rio de Janeiro to be highly exposed to moisture recycling dynamics.

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Rio de Janeiro, Brazil (*continued*)

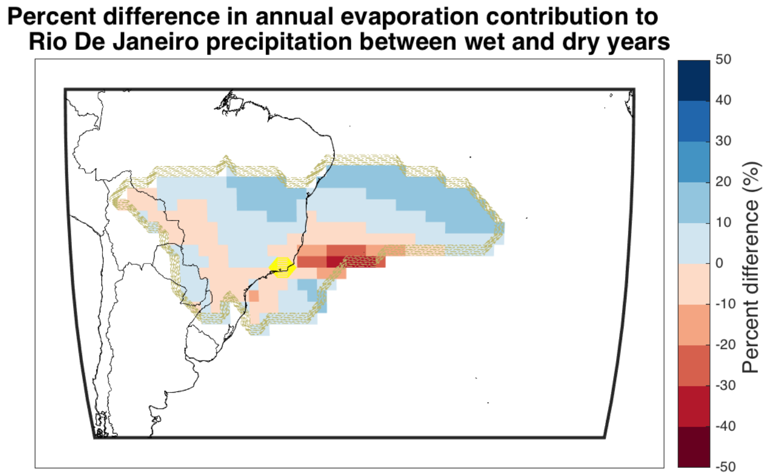

Figure S62: Percent difference in evaporation contribution between driest and wettest years.

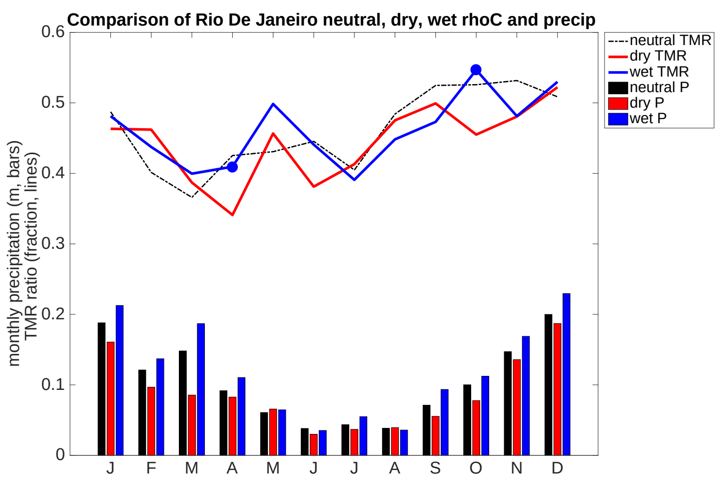

Figure S63: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Shanghai, China

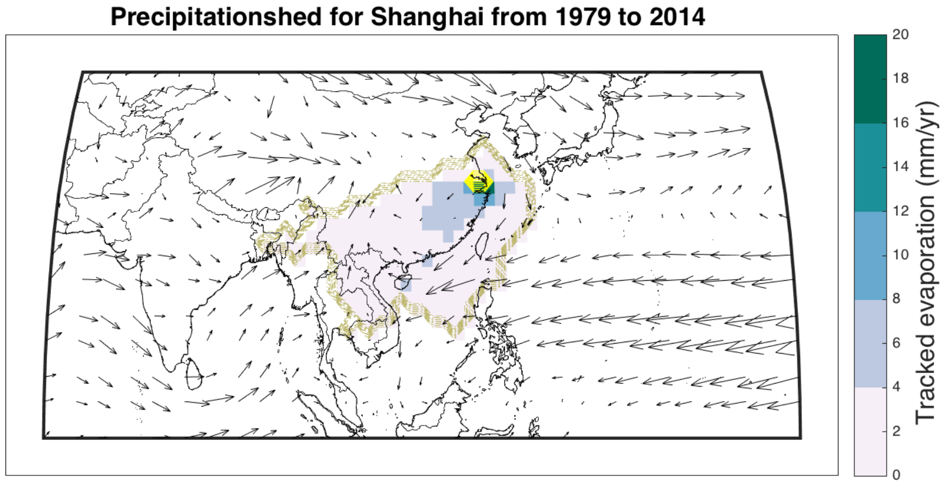

Figure S64: Shanghai precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Shanghai draws its drinking water from the Huangpu river, the final tributary of the Yangtze before it empties into the East China Sea. The basin is very small, and is subject to a great deal of pollution from the metropolitan area of Shanghai, as well as agriculture further upstream. Terrestrial moisture recycling is quite high, and is also sensitive to drier than normal conditions. Given the low availability of additional surface water resources, the importance of moisture recycling, and sensitivity to dry conditions, we consider Shanghai's water security to be highly exposed to moisture recycling dynamics.

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Shanghai, China (*continued*)

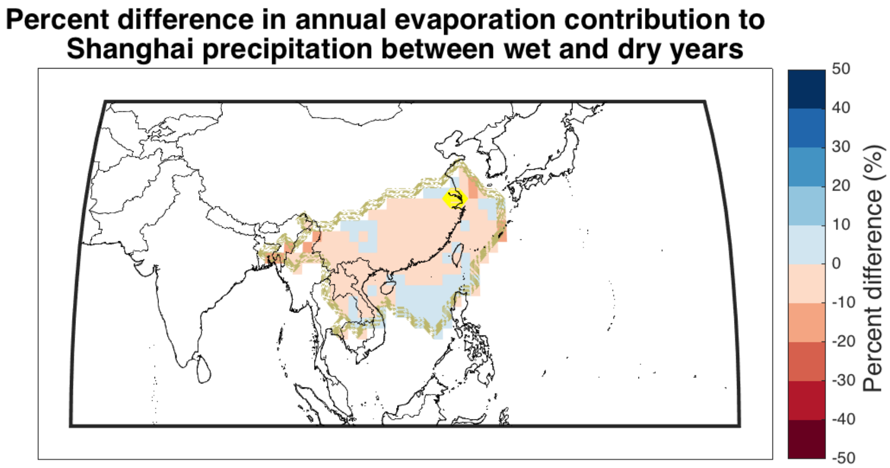

Figure S65: Percent difference in evaporation contribution between driest and wettest years.

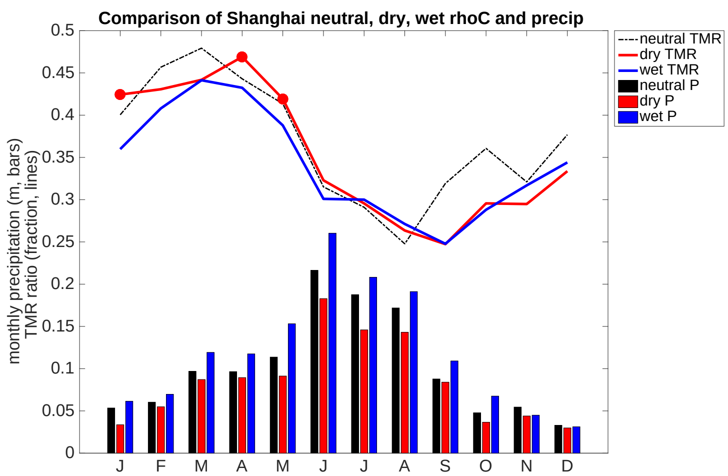

Figure S66: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Shenzhen, China

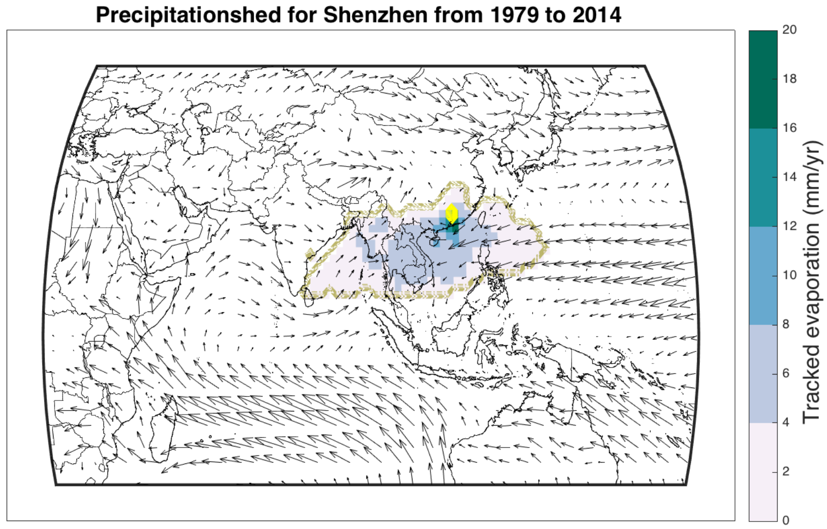

Figure S67: Shenzhen precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Shenzhen receives its water from the eastern tributary of the Pearl River (aka Dongjiang). It is a small catchment located to the northeast of the Pearl River Delta. It provides water to both Hong Kong and Shenzhen (as well as smaller settlements). The river is fully allocated and any variation in supply will be felt immediately by the users of water. Thus, any change in moisture recycling dynamics would be felt very quickly by the users of the Dongjiang, and we suggest that Shenzhen's water security is highly exposed to moisture recycling dynamics.

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Shenzhen, China (*continued*)

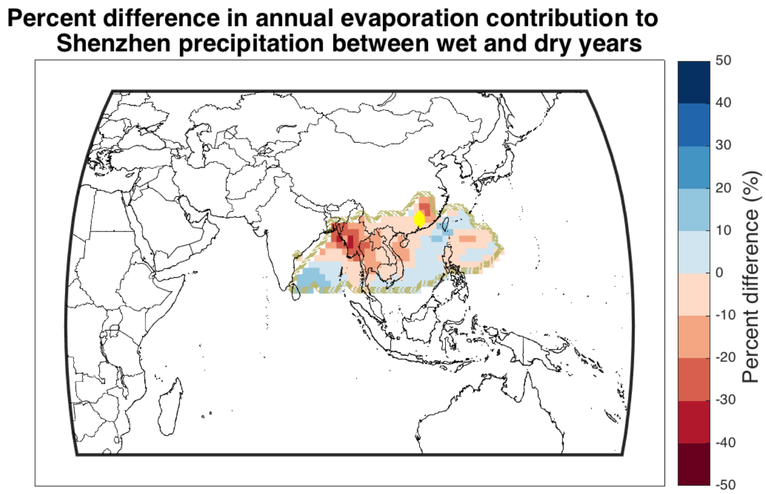

Figure S68: Percent difference in evaporation contribution between driest and wettest years.

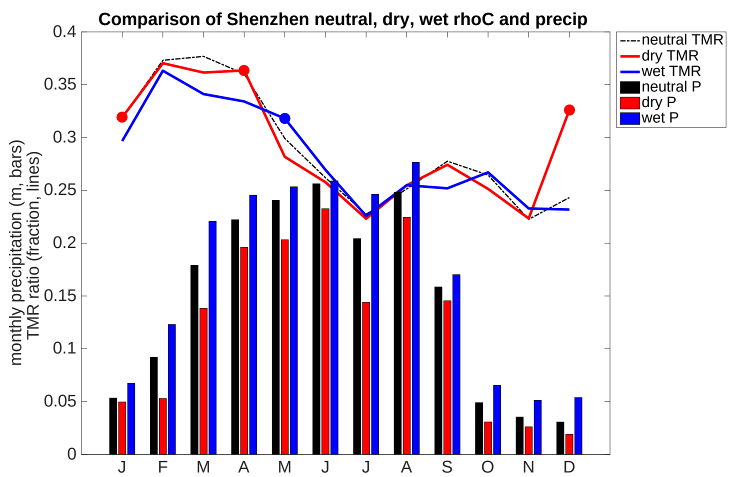

Figure S69: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Tokyo, Japan

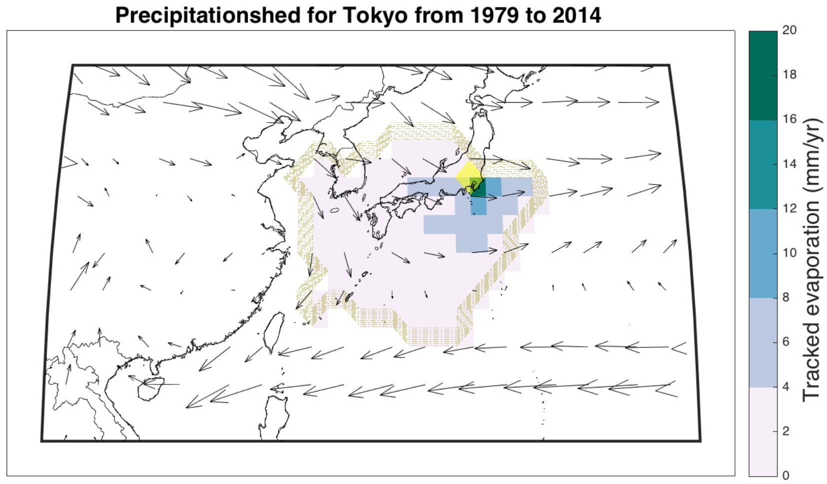

Figure S70: Tokyo precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Tokyo draws most of its water from the Arakawa River (78%) and Tama River (19%), with well-established conservation forests surrounding the watersheds to protect surface water quality. The interaction of forests and the watershed appear to be an important component to water security in Tokyo, and moisture recycling is relatively high, with vegetation supporting more than 10% of rainfall in the basin. Given the limited scope of expanded supply from other sources, we consider Tokyo's water security to be moderately exposed to its moisture recycling.

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Tokyo, Japan (*continued*)

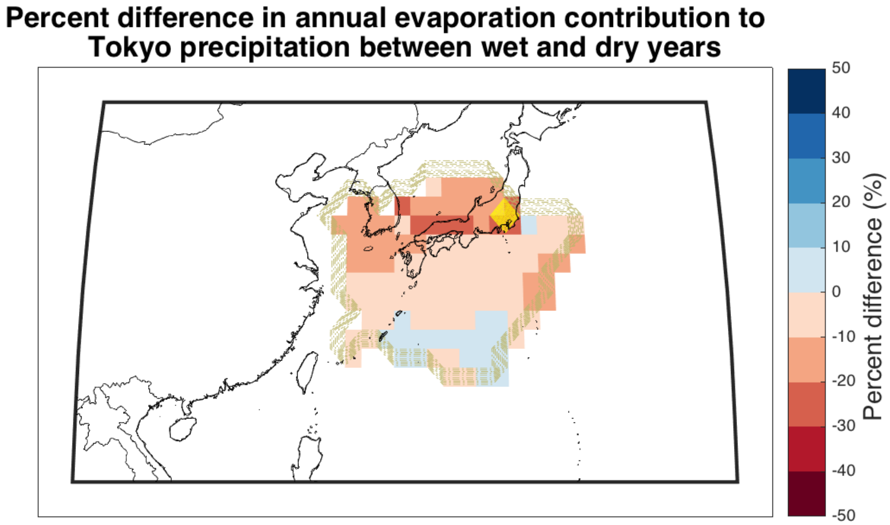

Figure S71: Percent difference in evaporation contribution between driest and wettest years.

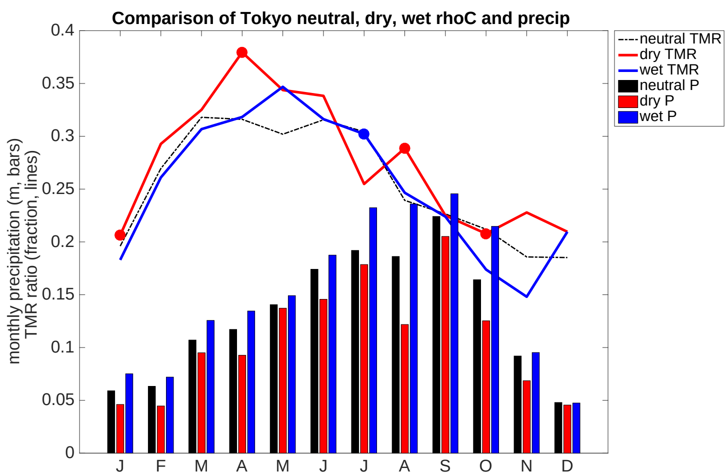

Figure S72: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.

Wuhan, China

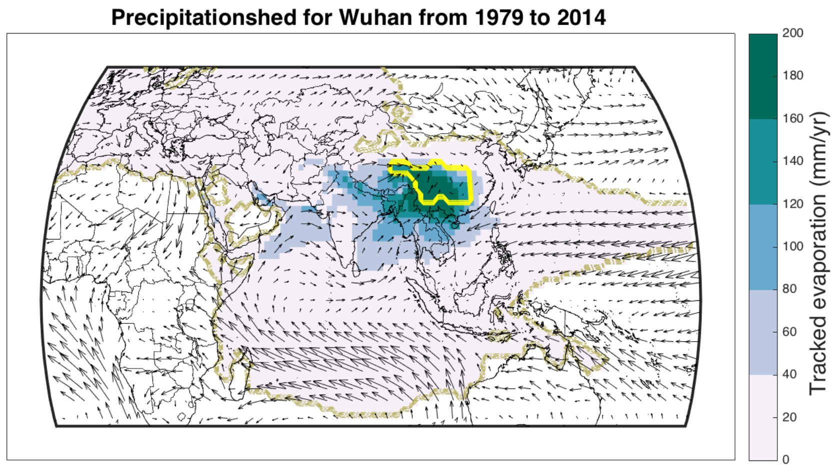

Figure S73: Wuhan precipitationshed, based on a core boundary (ranging from 1 mm/yr). Yellow lines enclose the sink region, and the prevailing winds are indicated to illustrate the average direction of the winds throughout the year.

Moisture recycling exposure analysis

Wuhan draws some of its water from the Hanjiang river, a tributary of the Yangtze, as well as from the Yangtze river proper. In recent years the Yangtze has experienced significant pollution from agriculture and industry leading to large-scale water supply shut-offs within the city. The basin experiences high moisture recycling, with more than 30% of moisture regulated by vegetation. Given the lack of additional water supply sources, due to overwhelming pollution, and the importance of moisture recycling, we consider Wuhan to be highly exposed to changes in moisture recycling.

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Wuhan, China (*continued*)

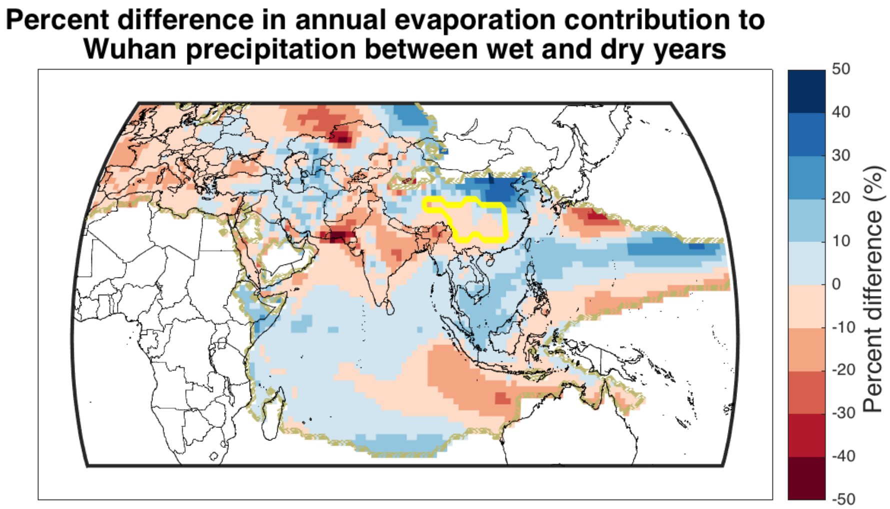

Figure S74: Percent difference in evaporation contribution between driest and wettest years.

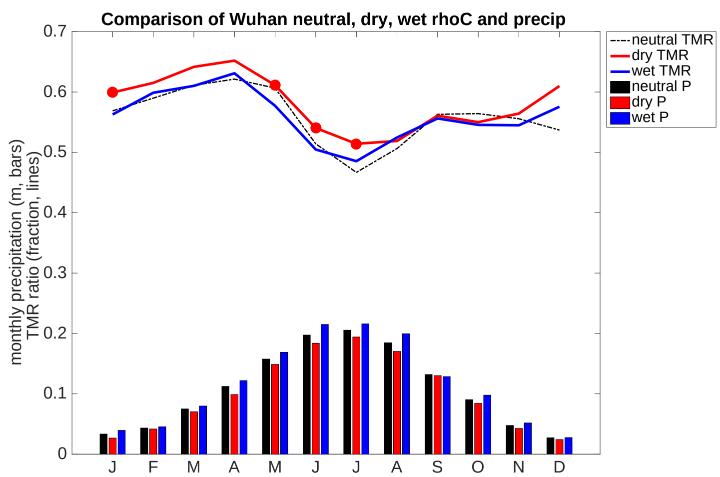

Figure S75: Summary of monthly average precipitation and terrestrial moisture recycling (TMR) during neutral, dry, and wet years. Note that the y-axis corresponds to both m/month of precipitation (represented by bars), and the fraction of precipitation originating from upwind land surfaces (represented by lines). The dots indicate significant differences for either dry or wet years during that month; see Methods in main article for further details.