Water Cycle Changes in Reanalyses

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Water Cycle Budget

The global water cycle's mass balance is expressed with the water budget equation:

$$P + Q_{in} = E + Q_{out} + \Delta S \quad (1)$$

where P is precipitation, Q_{in} is water flow into the Earth, E is evaporation (since we are at the global scale we will refer to it simply as evaporation for brevity, but we acknowledge it encompasses evaporation from soils, surface-water bodies, and plants), ΔS is water storage change in the land-ocean continuum (biological water, fresh lakes, ice, nonrenewable groundwater, oceans, permafrost, reservoirs, renewable groundwater, rivers, saline lakes, seasonal snow, soil moisture, and wetlands), and Q_{out} is water flow out of the Earth. All terms are averaged globally over a fixed time period (e.g., mm/year). At the global scale, due to Earth's gravity and temperature, water inflow or outflow leaking between the atmosphere and outer space is negligible compared with precipitation and evaporation and water storage change. Consequently, $Q_{in} \to 0$ and $Q_{out} \to 0$ leaving us with:

$$\Delta S = P - E \quad (2)$$

where ΔS represents a storage redistribution from the atmosphere towards the land-ocean continuum (positive), from the land-ocean continuum towards the atmosphere (negative), or steady state equilibrium (zero). Now, we define global water cycle intensity as:

$$GWCI = P + E \quad (3)$$

In this manner, intensity is defined as the total total flux of water exchanged between the atmosphere and the land-ocean continuum. This definition is in line with previous formulations in the literature[1,2]. Furthermore, different ways to integrate precipitation and evaporation to describe the hydroclimatic regime have been in use for over half a century now (e.g., Budyko curve[3]).

Water Cycle Kynematics

As established above, precipitation plus evaporation describes the water cycle intensity from a mass balance perspective by quantifying the total flux of water exchanged between the atmosphere and the land-ocean continuum. If we describe these atmospheric water fluxes from a kinematic perspective, we have two velocity vectors:

$$\vec{P}_{lon,lat} = P(x, y, z)$$
$$\vec{E}_{lon,lat} = E(x, y, z) \quad (4)$$

where, at any location on Earth's surface, $\vec{P}_{lon,lat}$ is the precipitation vector with magnitude P and $\vec{E}_{lon,lat}$ is the evaporation vector with magnitude E. These velocities are parallel to each other but are oriented in opposite directions. We define the direction from the atmosphere to the surface as positive and the opposite (from the surface to the atmosphere) as negative, then:

$$\vec{P}_{lon,lat} = P(0\hat{i},\ 0\hat{j},\ 1\hat{k})$$
$$\vec{E}_{lon,lat} = E\,(0\hat{i},\ 0\hat{j},\ -1\hat{k}) \quad (5)$$

Precipitation and evaporation are heavily intertwined through moisture recycling. Therefore, we could characterize their interdependence relationship by defining the velocity of the global water cycle as the Newtonian relative velocity of precipitation with respect to evaporation:

$$\begin{aligned}\overrightarrow{GWC_{lon,lat}} &= \vec{P}_{lon,lat} - \vec{E}_{lon,lat} \\ &= \boldsymbol{P}(0\hat{i},\ 0\hat{j},\ 1\hat{k}) - \boldsymbol{E}(0\hat{i},\ 0\hat{j},\ -1\hat{k}) \\ &= (0-0)\hat{i} + (0-0)\hat{j} + (\boldsymbol{P} - (-\boldsymbol{E}))\hat{k} \\ &= 0\hat{i} + 0\hat{j} + (\boldsymbol{P} + \boldsymbol{E})\hat{k} \\ &= (\boldsymbol{P} + \boldsymbol{E})(0\hat{i},\ 0\hat{j},\ 1\hat{k})\end{aligned} \quad (6)$$

where ***(P + E)*** is the magnitude of global water cycle velocity. Hence, we can safely ascertain that assessing changes in $P+E$ refers to acceleration or deceleration of the global water cycle.

The Precipitation-Evaporation Space

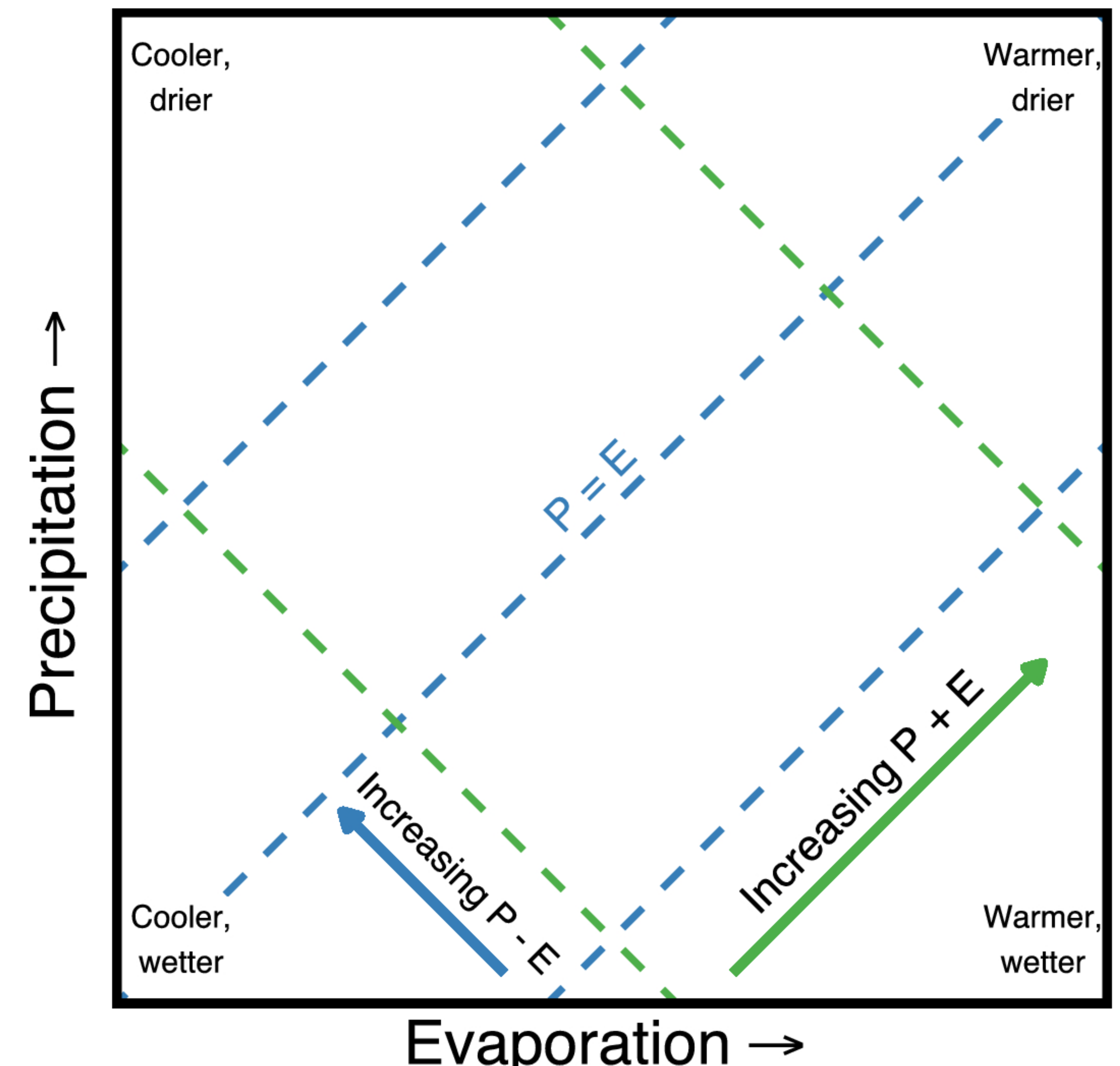

Fig. 1: The global water cycle regime in the precipitation–evaporation space. Vectors represent water cycle changes, where P is precipitation, and E is evaporation. Contours of equal $P - E$ (no change in water cycle storage) are shown as blue dashed lines, and movement across these lines (blue vector) describe changes in water cycle storage. Contours of equal $P + E$ (no change in water cycle intensity) are shown as green dashed lines, and movement across these lines (green vector) describe changes in water cycle intensity.

Including precipitation, evaporation, their difference, and their sum provides a synthesized visual of the overall response of the water cycle to global warming. The global water cycle regimes in this framework would be described in the precipitation–evaporation space by their precipitation and evaporation coordinates, and vectors represent changes between two periods (Fig. 1). By transforming the changes in the relationship of P and E to changes in $P-E$ and $P+E$, we can describe the water cycle dynamics in terms of atmospheric water storage and fluxes correspondingly. Precipitation and evaporation may increase, decrease, or remain constant. From equation (2), changes in atmospheric water storage ($P-E$) shown as blue contours are planes that increase from the bottom right (wetter) to the top left corner (drier). It is important to note that Huntington et al. (2018)[1] focused on terrestrial water storage, as such, the directions for drier and wetter are reversed therein. From equation (3), water cycle acceleration ($P+E$) is a plane shown as green contours that increases from the bottom left (cooler) to the top right (warmer). $P-E$ is negative to the right of the identity diagonal, zero along this line, and positive to the left of the line. At the global scale, negative values describe an increase in atmospheric water storage (wetter), positive values describe an increase in land-ocean water storage (drier), and zero describes steady-state equilibrium. $P+E$ increases describe shifts from cooler regimes into warmer ones.

Water Cycle Changes

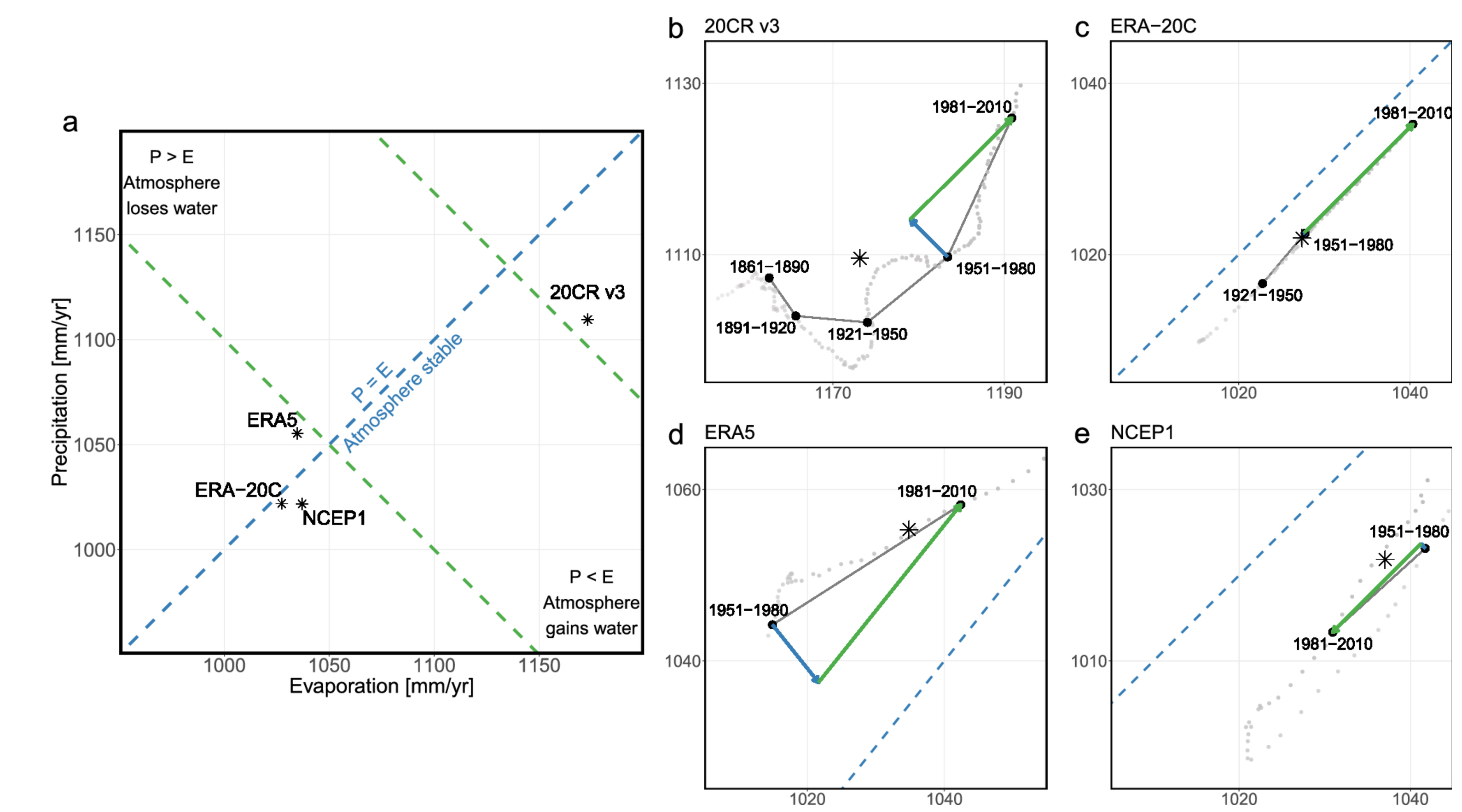

Fig. 2: The precipitation–evaporation space graphical framework for the assessment of global water cycle changes. P and E are global total precipitation and evaporation in mm/year. Contour of $P=E$ is shown as a blue dashed line (stable atmosphere). Contours of equal $P+E$ are shown as green dashed lines (equal water cycle intensity). Changes in $P-E$ and $P+E$ are shown as blue and green vectors correspondingly. Light gray points show the 30-year moving average trajectory, black points mark the labeled 30-year period of interest, and stars mark the position of the average for the full record of each reanalyses. I.e., 1836–2015 average for 20CR v3, 1900–2010 average for ERA-20C, 1950–2020 average for ERA5, and 1948–2020 average for NCEP1. (**a**) Relative position of reanalyses with respect to each other in the precipitation–evaporation space. (**b**) Zoomed in panel on the 20CRv3. (**c**) Zoomed in panel on ERA20C. (**d**) Zoomed in panel on ERA5. (**e**) Zoomed in panel on NCEP1.

References

1 Huntington, T. G., Weiskel, P. K., Wolock, D. M. & McCabe, G. J. A new indicator framework for quantifying the intensity of the terrestrial water cycle. J. Hydrol. 559, 361–372 (2018)
2 Weiskel, P. K. et al. Water use regimes: Characterizing direct human interaction with hydrologic systems. Water Resour. Res. 43 (2007).
3 Budyko, M. I. Climate and Life (Academic Press, 1974).

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