Anatomies of extreme Paraná River floods

Contributions of different time scales

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Introduction

The Paraná River has the third largest river discharge of South America and is located in the southeastern part of this continent (Figure 1). Occasionally, the Paraná flow can be about two to three times greater than its climatological value, causing major floods with high societal and economic impacts [1]. Although several studies had been undertaken to elucidate the climate forcings of extreme Paraná floods, there is still a need to perform a complete examination of all the different time scales and associated processes that are involved in the generation of these severe events.

Objective

To examine how flow changes with different time scales contributed to generate the four largest observed Paraná floods (1905, 1983, 1992 and 1998).

Data and method

The Paraná flow record used here consists of monthly mean discharges at Corrientes gauging station for the interval 1904-2010 (see station location in Figure 1 and raw flow data in top of Figure 2). This record (denoted by Q) is decomposed as follows using CEEMDAN, a method designed for nonlinear and nonstationary data [4]:

$$Q = \sum_{k=1}^{10} Ck + R,$$

where Ck are oscillatory modes (based on and derived from Q), and R is a residual secular upward trend. It is stressed that different modes Ck correspond to different time scales or oscillatory periods.

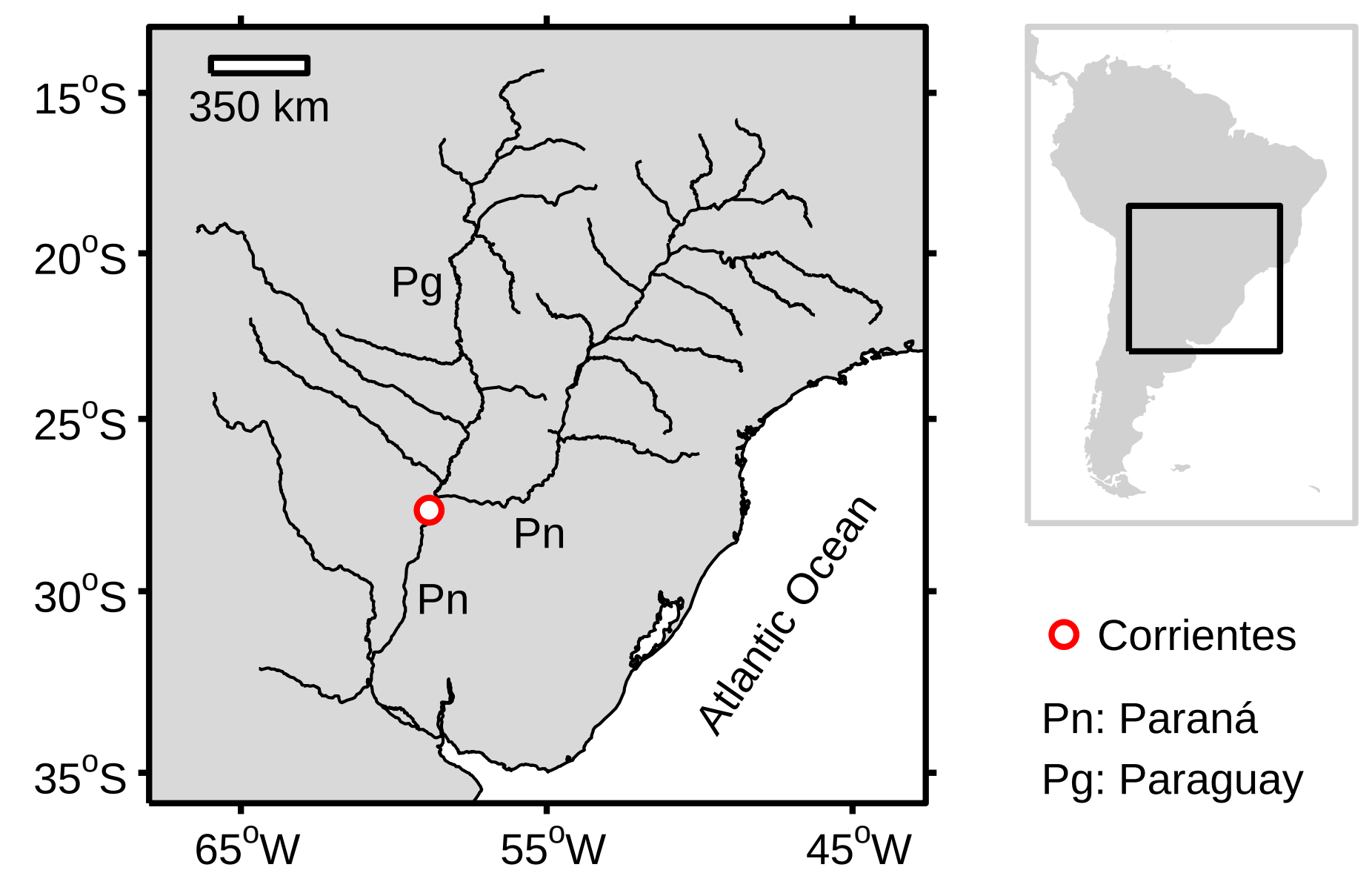

Figure 1: Drainage system of the Paraná River. Corrientes station is downstream of the Pn and Pg confluence.

Cycles and trend of Paraná flow

As shown in Figure 2, we successfully interpreted six oscillations or cycles, which are single modes or sums of modes, and the trend R (see detailed interpretations in [2, 3]). Note in Figure 2 that each oscillatory or trend change of flow is associated with a particular climate forcing.

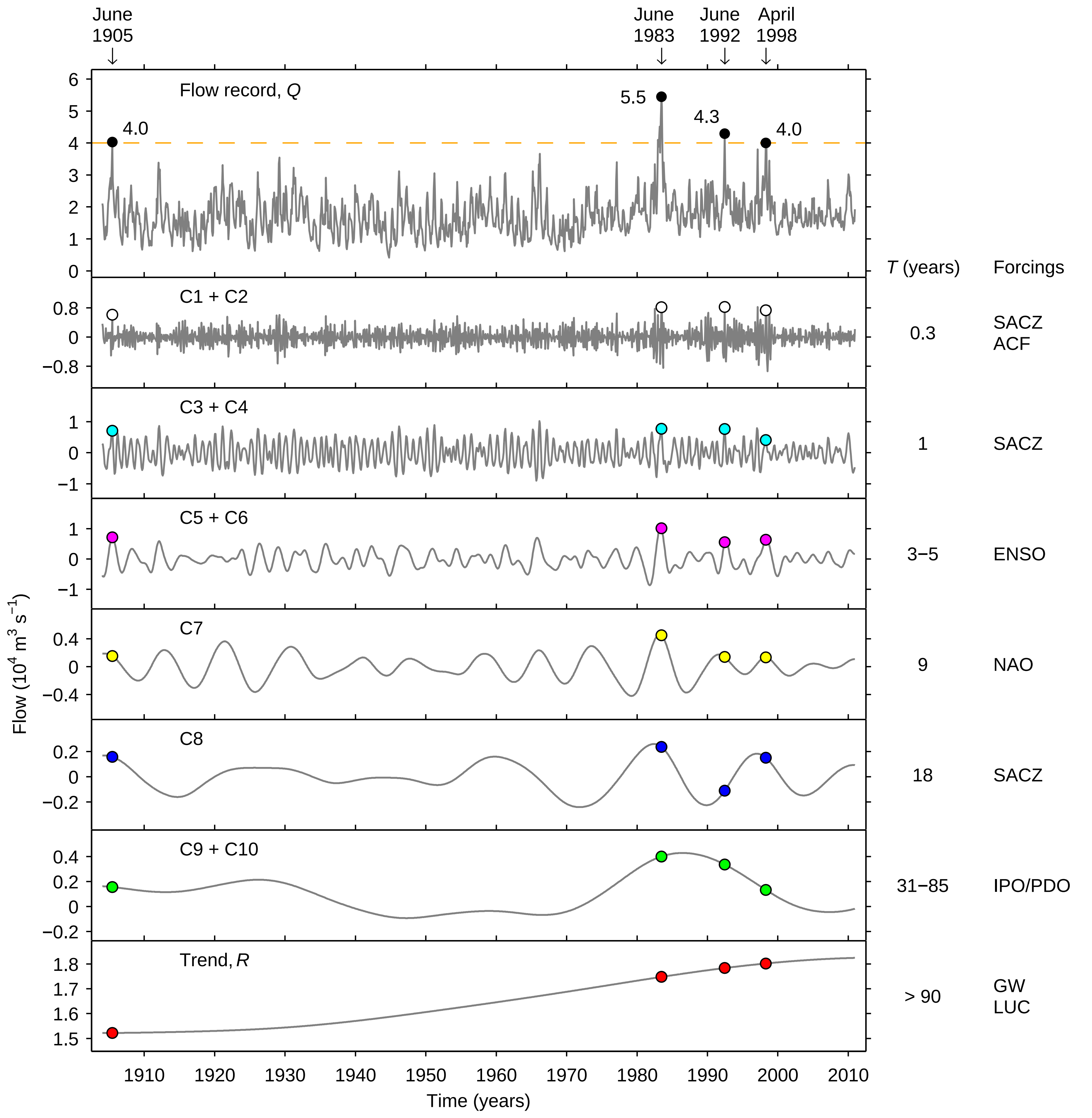

Figure 2: Paraná flow record at Corrientes station, its oscillations, and its trend. Circles indicate the time series elements corresponding to the times of extreme Paraná floods. Time scales (***T***) are shown and correspond to dominant oscillatory periods. Climate forcings are: South Atlantic Convergence Zone (**SACZ**), Atlantic cold fronts (**ACF**), El Niño/Southern Oscillation (**ENSO**), North Atlantic Oscillation (**NAO**), Interdecadal Pacific Oscillation/Pacific Decadal Oscillation (**IPO/PDO**), global warming (**GW**), and land use changes (**LUC**).

Flood anatomies

Flood-flow peaks are broken down into the contributions (flow anomalies) corresponding to the cycles and the trend that make up the variability of Paraná flow [3]. The resulting "flood anatomies" are shown in Figure 3 and reveal that all the flow oscillations contributed to generate all the extreme floods, except the 18-year cycle C8 that did not contribute to the 1992 flood. In most cases, contributions resulted from the occurrence of large cycle peaks at the times of the floods (Figure 2).

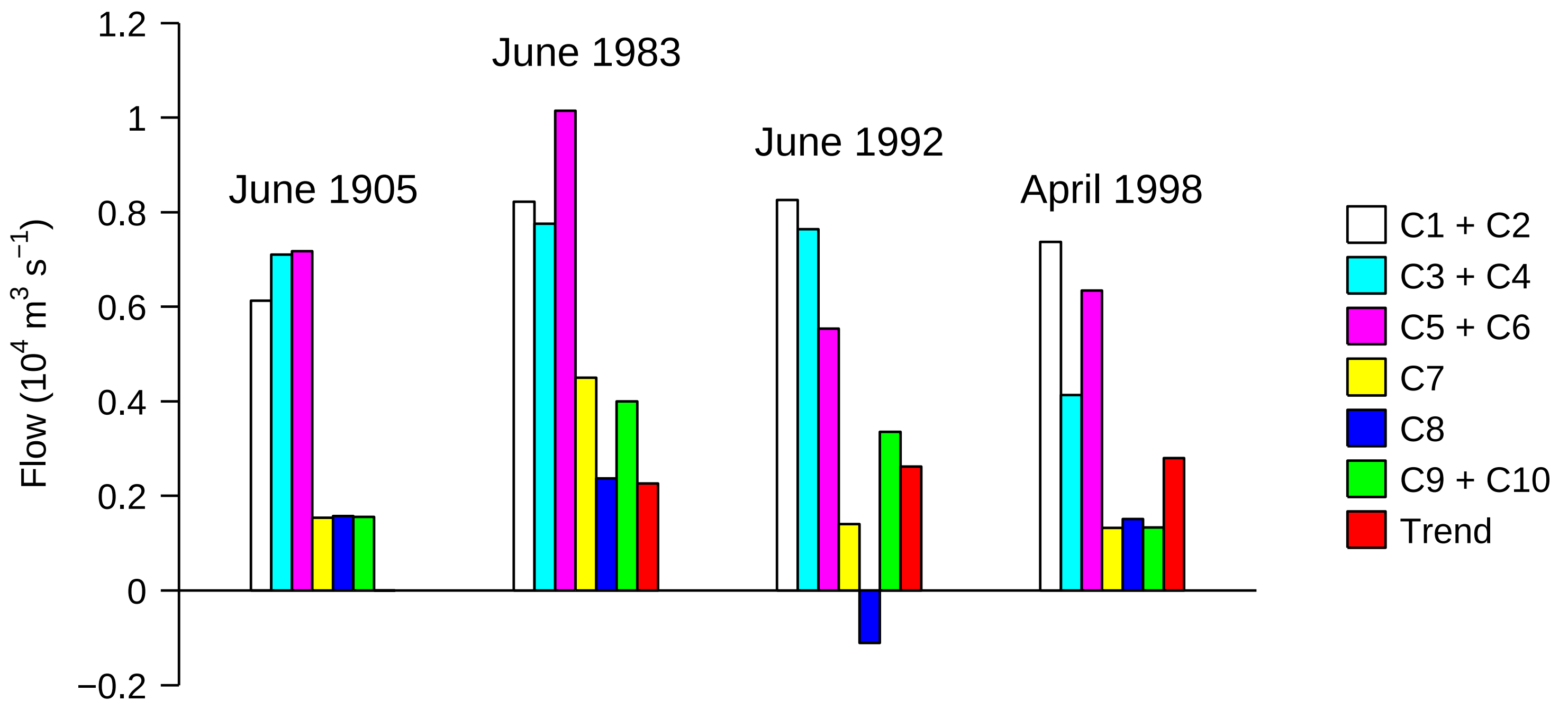

Figure 3: Contributions of flow oscillations and trend to extreme Paraná floods; these contributions are depicted by circles in Figure 2. Contributions of the upward trend are expressed as anomalies relative to January 1904.

The importance of interannual and longer cycles

Figure 4 shows that the four extreme floods coincided with the four largest peaks of the sum of interannual and interdecadal flow oscillations. Thus, the favourable conditions for extreme-flood formation were largely set by sporadic strong constructive intereferences between interannual and longer discharge cycles.

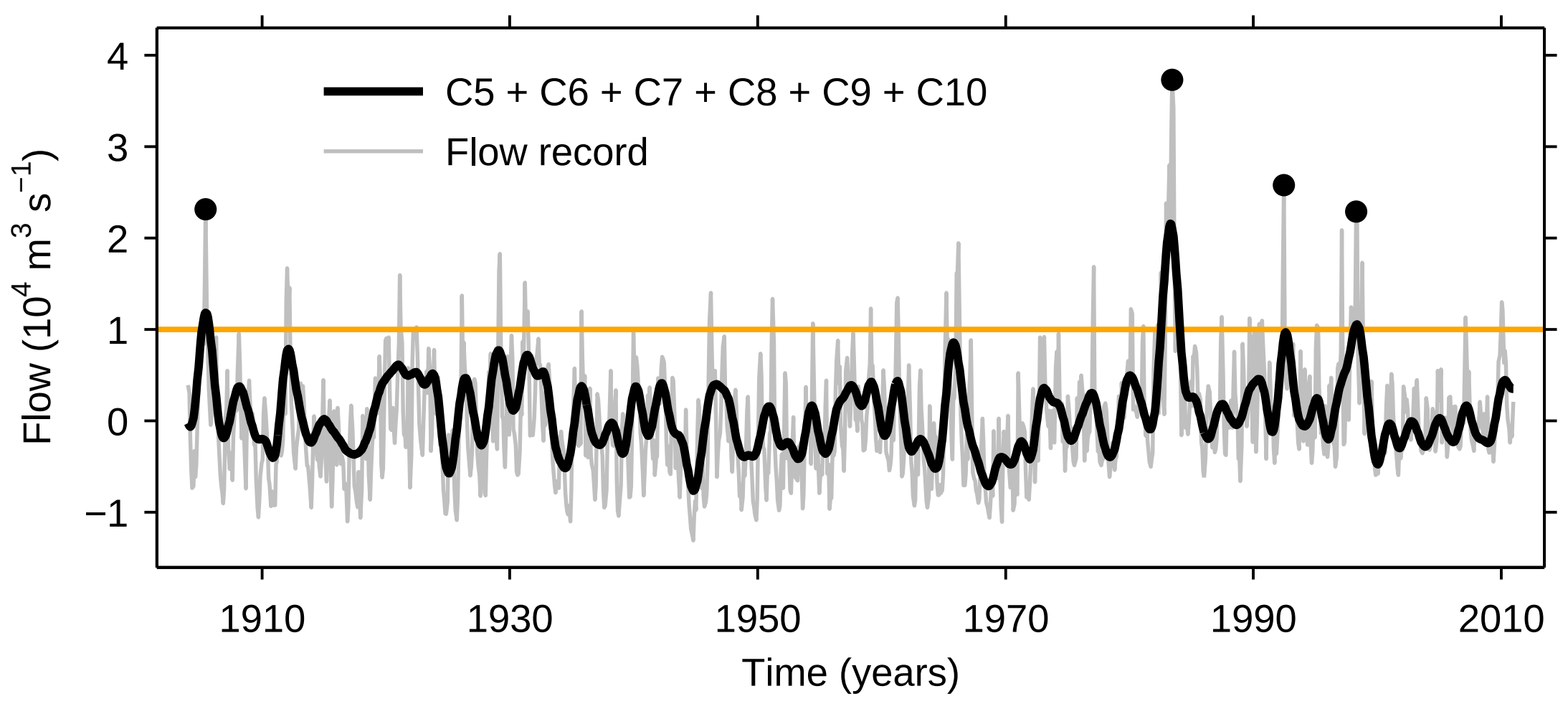

Figure 4: Paraná flow record (same of top of Figure 2 but with its mean subtracted) and the sum of the interannual-to-interdecadal flow cycles. Circles indicate extreme floods.

Why was the 1983 flood so extreme?

The interannual-to-interdecadal cycles C5 + C6, C7, C8, and C9 + C10 contributed more to the 1983 flood than to the other floods (Figure 3) because the largest peaks of all these cycles occurred approximately synchronously around 1983 (Figure 2). As seen in Figure 4, these aligned strong peaks added constructively in 1983 to generate an exceptionally large flow peak that had no analogue in the remaining years of the interval 1904-2010. Therefore, this one-in-a-century constructive interference between C5 + C6, C7, C8 and C9 + C10 caused the massive 1983 flood.

IPO/PDO versus the secular trend

The two most extreme floods (1983 and 1992) occurred at the top of the largest peak of the Pacific-related interdecadal cycle C9 + C10 (see Figure 2). As a result, the contributions of C9 + C10 to these two floods were larger than the secular trend increase in flow from the mid 1900s to the early 1990s (Figure 3). This suggests that the role of the IPO/PDO (Pacific forcing of C9 + C10) in extreme-flood formation would be more important than the role of the secular trend drivers, which are global warming and land use changes.

Conclusions

- Interannual-to-interdecadal flow cycles determined the favorable conditions for flood formation. Since these cycles could be predictable, years with high flood risk may be anticipated.
- The massive flood of 1983 resulted from an exceptionally strong constructive interference between flow cycles of 3-5, 9, 18 and 31-85 years, which are driven by different climate forcings.
- A Pacific-related flow cycle of 31-85 years played an important role in the formation of the two biggest floods (1983 and 1992).

References

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